Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2002/108 | **Document de recherche 2002/108**

Not to be cited without
permission of the authors * | Ne pas citer sans
autorisation des auteurs *

At-sea observer coverage for catch monitoring of the British Columbia hook and line fisheries

Contrôle en mer des prises à la ligne et hameçon en Colombie-Britannique

R. Haigh, J. Schnute, L. Lacko, C. Eros, G. Workman, B. Ackerman

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, B.C. V9T 6N7

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

This document is available on the Internet at:

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883

© Her Majesty the Queen in Right of Canada, 2002
© Sa majesté la Reine, Chef du Canada, 2002

Canada

Abstract

This paper takes an initial look at the hook and line observer data and is exploratory. It provides several methodologies for calculating the total catch of IRF species by the hook and line fisheries: (i) the adjustment of landed IRF catch using observed discard rates, (ii) the prediction of total IRF catch from landed target catch, and (iii) the extrapolation of observed catch to total catch, with estimates of precision from simple random sampling theory. While the latter methodology is sound in principle, the limited availability of data and the low levels of observer coverage lead to highly biased estimates of total catch with enormous confidence intervals. Levels of observer coverage needed to attain target precision levels are derived based on the available set of observer logs. Because the current low levels of coverage are insufficient to characterize the underlying fisheries, estimates of catch and coverage derived should not be used for management purposes.

Résumé

Le présent document porte sur un examen préliminaire des données recueillies par des observateurs sur la pêche avec ligne et hameçon. Y sont présentées plusieurs méthodes pour calculer les prises totales d'espèces visées par le forum régional intégré (IRF), soit : (i) le rajustement des prises IRF débarquées en fonction des taux observés de rejet à la mer, (ii) la prédiction des prises IRF totales d'après les prises débarquées d'espèces-cibles et (iii) l'extrapolation des prises observées pour obtenir les prises totales et des estimations de la précision reposant sur la théorie de l'échantillonnage aléatoire simple. Bien que cette dernière méthode soit fiable en principe, le peu de données disponibles et le faible niveau de présence d'observateurs en mer ont résulté en des estimations fortement biaisées des prises totales montrant des intervalles de confiance très vastes. Les niveaux de présence d'observateurs requis pour obtenir les niveaux de précision visés sont établis d'après la série disponible de journaux de bord des observateurs. Les faibles niveaux actuels de présence d'observateurs étant insuffisants pour caractériser les pêches ciblées, les estimations des prises et du niveau de présence d'observateurs dérivées ne devraient pas être utilisées à des fins de gestion.

Table of Contents

1. Introduction 1
2. Data sources 2
3. Comparison of fisher logs to observer logs 4
4. Discard analysis 4
5. Simulated observer coverage 7
6. Discussion 10
7. Recommendations 13
Acknowledgements 13
References 14
Appendix A. Summary of sampling theory 47
Appendix B. Current status of observer programs on Canada's west coast 50
Appendix C. Request for advice 54

List of Tables

Table 1. Catch estimate data sources for H&L 15
Table 2. Missing logbook trip submissions 16
Table 3. Management regions based on PFM areas 16
Table 4. Number of observer sets by gear type at 100-m depth intervals 17
Table 5. Number of observer sets by gear type at 50-m depth intervals 18
Table 6. Observer populations defined 18
Table 7. IRF discard rates & catch per retained target – halibut longline 19
Table 8. IRF discard rates & catch per retained target – ZN longline 20
Table 9. IRF discard rates & catch per retained target – ZN handline 21
Table 10. IRF discard rates & catch per retained target – WCVI Schedule II 22
Table 11. Interpolated observer coverage – halibut longline 23
Table 12. Interpolated observer coverage – ZN longline 24
Table 13. Interpolated observer coverage – ZN handline 25
Table 14. Interpolated observer coverage – Schedule II 26
Table 15. Observer coverage by fishing year 26
Table 16. Mean observer weight per fish 27
Table 17. Estimated total catch – ZN longline 28

Table A1. Parameters for a population of size N 47
Table A2. Additional parameters for a population of size N, ratio estimates 48
Table A3. Properties of the estimates in Table A2 49
Table B.1. Observer coverage target levels by fishery 53
Table B.2. Levels of coverage achieved, 1996-2000 53

103-07483/

List of Figures

Fig. 1. Number of species per pseudoset 29
Fig. 2. Comparison of catch pieces between fisher and observer logs 30
Fig. 3. Comparison of catch weight between fisher and observer logs 31
Fig. 4. Estimates: $\hat{C}$, $\hat{C}_r$ and their CVs – Halibut longline in QCI 32
Fig. 5. Observer coverage simulation – Halibut longline in QCI 33
Fig. 6. Observer coverage simulation – Halibut longline in PR 34
Fig. 7. Observer coverage simulation – Halibut longline in CC 35
Fig. 8. Observer coverage simulation – Halibut longline in WCVI 36
Fig. 9. Observer coverage simulation – ZN longline in QCI 37
Fig. 10. Observer coverage simulation – ZN longline in PR 38
Fig. 11. Observer coverage simulation – ZN longline in CC 39
Fig. 12. Observer coverage simulation – ZN longline in WCVI 40
Fig. 13. Observer coverage simulation – ZN handline in QCI 41
Fig. 14. Observer coverage simulation – ZN handline in PR 42
Fig. 15. Observer coverage simulation – ZN handline in CC 43
Fig. 16. Observer coverage simulation – ZN handline in WCVI 44
Fig. 17. Observer coverage simulation – Schedule II longline in WCVI 45
Fig. 18. Observer coverage simulation – Schedule II troll in WCVI 46

At-sea observer coverage for catch monitoring of the British Columbia hook and line fisheries

1. Introduction

Recent conservation concerns about inshore rockfish (IRF) species along the British Columbia (BC) coast have highlighted the need for more accurate estimates of total catch (retained plus discarded) from the hook and line fleet. Additionally, various departmental policy initiatives (e.g., *New Directions*, *Selective Fishing*, *Allocation for Pacific Salmon*, *Pacific Fishery Monitoring and Reporting Framework*) have stated that effective catch monitoring and standards are necessary, especially if Canada is to meet international obligations.

Therefore, to obtain more information on catches at sea the Department of Fisheries and Oceans (DFO) initiated at-sea catch monitoring programs (partial coverage starting in 1999) for commercial hook and line (H&L) groundfish fisheries in BC. The primary objective of the at-sea observer programs (ASOPs) was the collection of data to develop estimates of at-sea discards of inshore rockfish – (1) yelloweye rockfish *Sebastes ruberrimus*, (2) quillback rockfish *S. maliger*, (3) copper rockfish *S. caurinus*, (4) china rockfish *S. nebulosus*, (5) tiger rockfish *S. nigrocinctus*, (6) canary rockfish *S. pinniger*, (7) silvergray rockfish *S. brevispinis*, (8) rougheye rockfish *S. aleutianus*, (9) shortraker rockfish *S. borealis*, (10) shortspine thornyhead *Sebastolobus alascanus*, (11) Pacific ocean perch *Sebastes alutus*, (12) yellowmouth rockfish *S. reedi*, (13) redstripe rockfish *S. proriger*, (14) yellowtail rockfish *S. flavidus*, (15) black rockfish *S. melanops*, and (16) widow rockfish *S. entomelas*. While a dockside monitoring program (DMP) accounts for all landed catch, anecdotal evidence suggests that at-sea releases of IRF in these fisheries are potentially significant. The lack of discard information currently limits DFO's ability to estimate total removals of IRF from coastal waters. Consequently, management is compromised when trying to ensure that catches remain within sustainable total allowable catch levels.

The partial coverage at-sea observer programs are currently operational in the following commercial licence category groundfish fisheries: L (halibut hook and line), K (sablefish hook and line and trap), Outside ZN (rockfish hook and line), Schedule II (dogfish and lingcod hook and line), and T (Option B trawl, Option A mid-water trawl for hake).

The target levels of partial coverage for the ASOPs varies by fishery, but generally covers 10-15% of the fishing effort (vessel days and boat trips). This level of coverage was developed without input from science, and consequently does not follow any guidelines that might address the accuracy and precision of total catch estimates. To establish observer coverage levels objectively, DFO needs to know the precision associated with various levels of coverage.

This paper takes an exploratory look at the H&L observer data. We first compare observer logs to fisher logs (Section 3). We then suggest several methodologies that might be used to calculate the total catch (retained + discarded) of IRF species by the H&L fisheries: (i) adjustment of DMP landed catch using observed discard rates (Section 4), (ii) prediction using empirical ratios of IRF total catch to target species retained catch (Section 4), and (iii) extrapolation of observed catch to total catch, with estimates of precision from simple random sampling theory (Section 5).

Reader Caveat: Levels of observer coverage to attain target precision levels are derived based on the available set of observer logs. Most of the fisheries delimited in this study are not adequately represented by observer logs. Consequently, catch estimates and coverage levels herein are presented to illustrate the methodologies only.

2. Data sources

Commercial hook and line data are currently housed in a relational database called PacHarvHL (http://pacpbsgfdb/sql/PacHarvHL.htm), which can be accessed by any DFO employee provided s/he has permission from the database administrator. The H&L fisheries include those targetting halibut, rockfish (ZN), and dogfish and lingcod (Schedule II). The primary fishing event data come from fisher logs that contain bridge log and catch information recorded by individual skippers. Observer logs, on the other hand, are supplementary fishing event records taken independently by onboard observers and should mirror the fisher logs closely. Observer logs are available since 1999 when the programs were initiated, and coverage of the various H&L fisheries is partial (~10-15% days fished).

Although we use the term "set" in this paper, the concept of "set" is more appropriately captured by the term "fishing event". In the handline and troll fisheries, fishing events are described by (i) fishing location and (ii) the start and end times of fishing activity. The definition of fishing activity is highly dependent on each fisherman. For example, if a particular reef is occupied all morning, one fisherman might record this as one fishing event while another fisherman might describe it as multiple events depending on factors like reef topography, onboard rest breaks, bait changes, etc. Longline sets, on the other hand, are defined in a less arbitrary manner: (i) start and end locations and (ii) soak time of each string of gear.

Further, how an observer defines a set can be different than how a fisherman defines it. Yet, even if the two parties agreed on set delimitation, there is no guarantee that the observed set is recorded with the same number as the corresponding fisher log. This is because the log sheets that skippers use are not designed to include entries for set number. Fisher sets are assigned *ex post facto* by the database load routine to reflect the fishing date and the order in which data-entry operators keypunched the log sheets. This assignment will generally be independent of how an observer might number the sets s/he observed.

Aside from the non-rigorous cross-referencing of set numbers, other quirks of the H&L fishery serve to confound the data:

- If a vessel is too small to accommodate an observer, s/he will often transfer from one boat to another and record parts of trips. This precludes using trip as the observed sample unit.
- Skippers sometimes stop recording fisher logs if the set is being observed and recorded. Subsequently, there is no way to compare fisher logs to observer logs.
- Skippers sometimes record the catch of multiple sets as one set.
- While most observer data have been collected in the halibut fishery, there are no corresponding fisher logs in PacHarvHL. The latter must come from the International Pacific Halibut Commission (IPHC) in Seattle through a significant bureaucratic process.
- Catch is primarily recorded as "pieces" by both skippers and observers. Catch weight, on

the other hand, is estimated from pieces. Fisher log catch weight is calculated from fisher log catch pieces by the database load routine using *ad hoc* annual Pacific Fisheries Management (PFM) area-average conversions (weight fish^{-1}). Observer log catch weight is estimated onboard by observers who use a variety of methods including observer-specific piece-to-weight conversion factors.

Currently, data for estimating total catch come from a variety of sources (Table 1). In the database PacharvHL, the table *D_Official_Catch* contains total catch and effort estimates generated by an algorithm that allocates DMP landed catch (at the trip level) to fisher log sets using species proportions recorded by the H&L logbook program. If DMP catch is recorded where no fisher log exists, the landed catch is allocated to an unknown fishing event labelled "999". Sometimes whole trips are missing from the fisher log database (Table 2).

Obviously, this post-allocation algorithm can only be used where the two data sources overlap (ZN: 1995-2002; Schedule II: Apr 2001-2002). While DMP landed weights are considered accurate, they do not account for discards. Starting April 2001, the logbook program required an estimate of discards, which has been incorporated into *D_Official_Catch*. However, compliance is a problem, and it is best to assume that discarded catch is not known.

Data from the DMP exist for the Schedule II fishery (1996-Mar 2001) without concurrent logbook records. Prior to the DMP, catch and effort estimates are available from the fisher log records in PacHarvHL for the ZN fishery (1986-1994). This time series contains data recorded at the fishing event level (Haigh and Richards 1997).

Fishing effort can be described as (i) the duration that fishing gear is in the water, (ii) the total number of hooks used during a set, or (iii) the number of fishing events referred to as "sets" that occur during a trip. Not all data sources contain sufficient information to delimit each measure of effort (Table 1). Additionally, logbook records contain missing or inaccurate information on effort (Yamanaka and Kronlund 1997). For example, fishing events may be recorded as one fishing event per day, when in fact, many fishing events have occurred during that day.

For the Halibut fishery, total catch and effort (at the trip level) can be obtained in the PacHarvHL DMP data tables (1998-2002). A separate Halibut DMP relational database currently contains catch and effort for 1991-1997. These historic data will be incorporated into the PacHarvHL DMP tables in the near future. Otherwise, fisher log records are maintained in a database by the IPHC. It is questionable whether these fisher logs record all halibut sets. Additionally, the rockfish catch on submitted fisher logs is only available in the IPHC database from 2002 on.

For the analysis of discards (Section 4) and observer coverage (Section 5), we treat each set of observer logs that delimit a regional fishery as a discrete population. We define a regional fishery by a unique combination of (i) fishery type, (ii) gear type, and (iii) management region (Table 3). Additionally, the populations are stratified by depth intervals (longline: 4 intervals of 100 m; handline/troll: 4 intervals of 50 m; the deepest interval also includes any sets deeper than 400 m and 200 m, respectively). Due to the limited amount of observer data, we do not stratify by time in this paper; however, we could certainly delimit the records by fishing year, for instance. The distribution of observer logs in the regional fisheries stratified by depth

(Tables 4-5) suggests that 14 of 36 possible observer populations (3 fishery types, 3 gear types, 4 regions) contain enough information for analysis (Table 6). The number of sets used in these 14 populations were further qualified to have some measure of fishing effort (number of hooks or duration of set). Many of the resultant observer populations are too small to represent the regional fisheries accurately; however, for the sake of the exercise we use them.

3. Comparison of fisher logs to observer logs

The problems discussed in Section 2 concerning the fisher logs and observer logs preclude any meaningful comparison between the two log types. We therefore derived "pseudosets" that attempt to match fisher sets to observer sets based on (i) trip ID, (ii) fishing date, and (iii) catch of the dominant species. This is not a process that can easily be automated and consequently involves a fair amount of manual processing. In some cases, fishermen recorded multiple sets as one set so that a pseudoset for the corresponding observer logs necessarily rolls up multiple observer log records. Note that pseudosets were only used in this paper for comparisons of catch between the two log types. At the time of writing, most observer logs came from the Halibut fishery; however, no corresponding fisher logs were available electronically. Consequently, pseudoset comparison can only be made for the ZN and Schedule II fisheries.

An initial look at the data simply plots the cumulative frequency of the number of species recorded per set (Fig. 1). The ZN logs generally recorded more species than did the Schedule II logs. Further, observers recorded more species than did the skippers – ZN: median = 8 vs. 5, respectively; Schedule II: median = 3 vs. 2, respectively.

To compare the catch (retained + discarded) of IRF species recorded by the two log types, we combined the ZN and Schedule II data. While fisherlogs are now supposed to record discards, they essentially still reflect retained catch. We might therefore expect that observer logs record more pieces than do fisher logs. However, total catch as pieces from the two log types shows a close correlation, at least for the dominant IRF species (Fig. 2). Scatter about the 1:1 line is most evident for quillback, copper, and shortraker rockfish. Simple regression lines through the data show no consistent anomalies. Statistically, observers reported more catch than fishermen did ($\beta > 1$) for quillback, china, and tiger rockfish. Catch comparisons for bycatch (chiefly discarded) rockfish species other than the 16 IRF species are not useful because most fisher logs do not report discarded catch.

Catch expressed in weight is much less comparable between the two log types (Fig. 3). This stems from the use of various conversion factors applied to log pieces, depending on log type and other conditions. Catch weights derived thus appear to be grossly different between the two log types for some species (e.g., rougheye rockfish). The curves in Fig. 3 suggest that piece-to-weight conversion factors should be reviewed. Ideally, a set of standard conversion factors would be derived through research and applied by all parties.

4. Discard analysis

Using the 14 regional fisheries outlined in Section 2 (Table 6), we estimate the discard rate d of each IRF species from observer logs (Tables 7-10). The distribution of discard rates by

set does not follow a normal distribution. In most sets, fishermen retain all IRF species (e.g., "p (0)", Table 7). If they discard IRF, they are likely to discard them all (e.g., "p (1)", Table 7). The degree of this duality is characterised by how quickly $(p_0 + p_1) \rightarrow 1$.

If $(p_0 + p_1) < 1$, "high-grading" occurs where only premium marketable fish are kept. If the distribution of individual discard rates were normal, we could simply take the mean of the discard rates. However, for this paper we calculate the species discard rate d for the fishery as:

$$(4.1) \qquad d = \frac{\sum_{i=1}^{N} C_{D_i}}{\sum_{i=1}^{N} C_{T_i}},$$

where C_{D_i} = discarded catch weight from set i, C_{T_i} = total catch weight in set i, and N = number of sets in the fishery. (Note that this calculation could be performed at the stratum level, e.g., within depth bands). Observer catch weights are used to calculate discard rates, despite the errors introduced by observer piece-to-weight conversion factors, for two reasons. First, if high-grading occurs then a kept piece is not equivalent to a discarded piece. Second, DMP landings are measured as weight so that any discard adjustment needs to be weight-based. Bootstrapping (4.1) provides empirical 95% confidence limits.

If $d = 1$ in (4.1) there is no information on how landed catch might be adjusted. An alternative measure to the discard rate is the ratio of IRF catch to target retained catch. At the very least, the H&L fisheries are represented by measures of retained target catch, which is most accurately measured by DMP landings. The ratio of IRF catch to retained target can use either discarded IRF catch or total IRF catch. As the latter is ultimately the value sought by resource managers, we calculate the ratio for each species in each of the 14 fisheries as:

$$(4.2) \qquad g = \frac{\sum_{i=1}^{N} C_{T_i}}{\sum_{i=1}^{N} G_i},$$

where C_{T_i} = total catch weight of one IRF species in set i, G_i = retained catch of the target species in set i, and N = number of sets in the fishery. The target species G are as follows: Halibut → halibut, ZN → sum of 16 IRF species, Schedule II → lingcod + dogfish. Bootstrapping (4.2) provides empirical 95% confidence limits.

Discard rates in the halibut longline fishery (Table 7) are substantial, presumably because this fishery is targetting halibut with license conditions that allow limited retention of IRF species. The highest concentration of halibut longline observer logs occurs in the QCI region where d ranges from 0 to 70%. However, these rates are highly species-specific and in some cases quite variable (e.g., copper rockfish $d_{95\%CI}$ = 0.23-1.00). The sizeable discard rates are perhaps put into perspective by examining the ratio of IRF catch to target retained catch (Table 7). For most IRF species, the catch per tonne of halibut is generally < 5kg. The two most important bycatch IRF species appear to be yelloweye and rougheye rockfish with ratios in the

region of 20-30 kg/t.

In contrast, the ZN fisheries, both longline (Table 8) and handline (Table 9), experience virtually no discarding ($d < 3\%$). As the ZN fishery is directed on IRF species, this is perhaps no great revelation. However, the rates appear to be so low that we might be suspicious of an "observer effect" where the skippers retained more IRF species than they would have without an observer on board (i.e., the skippers reduced their tendency to high-grade). The observer effect, if present, introduces a serious bias that cannot be resolved easily.

The catch per ZN target ratios provide species composition summaries for each of the regional fisheries, if nothing else. The QCI ZN handline fishery (Table 9) appears to be anomalous with $d \to 1$. The ratios of catch per target in this fishery are also ridiculously out of alignment with values seen in the other regional ZN fisheries. No reasons are given; data errors are suspected.

Finally, the Schedule II fisheries that target lingcod and dogfish basically discard all their IRF catch (Table 10). The troll fishery sometimes keeps all its rockfish bycatch. None of the records show evidence of high-grading (i.e., $p_0 + p_1 = 1$ always). The number of sets is too low to say whether this behaviour is consistently exhibited. IRF catch per target catch is low for all observed IRF species.

It can be argued that DMP landings provide minimum estimates of known IRF removals. Using this base, we might consider scaling up the landings using observed discard rates (Tables 7-10). The rates might change from year to year but they can be easily re-calculated for use by assessment personnel and/or managers. As an example, suppose that the DMP landing of yelloweye rockfish in QCI by halibut longline fishermen is 10,000 pieces. The discard rate for this species in this regional fishery is 0.069 (Table 7). Discards can be calculated as:

$$C_D = dC_T, \tag{4.3}$$

where d = discard rate, C_T = total catch. The retained catch is simply:

$$C_R = C_T - C_D. \tag{4.4}$$

Substituting (4.3) into (4.4), total catch can be calculated:

$$C_T = \frac{C_R}{1-d}. \tag{4.5}$$

In our example, the total catch of yelloweye rockfish in this fishery would be calculated as 10,741 pieces. The 95% confidence interval for d is 0.048-0.095. Simply plugging these limits into (4.5) suggests a total catch ranging from 10,504 to 11,050 pieces; however, the confidence profile is specific to d, not to C_T.

The proportion of sets where the discard rate of yelloweye rockfish is 0% and 100% is 0.847 and 0.081, respectively (Table 7). This leaves $(1-(0.847+0.081))\times 666 = 50$ sets where skippers made some decision on which fish to discard and which to keep. The variability of

discard rates in the halibut fishery is generated by various retention options. For instance, one fisherman might be allowed to retain x% while another is allocated a further y% if he has a concurrent ZN license.

Aside from the variability in discard rates, this method becomes useless if the discard rate is 100% (the DMP landing of the IRF species will be 0 pieces). Scaling up is impossible – plug d=1 into (4.5) – and the total catch of this species remains unknown. In this case, the ratio of IRF catch to retained target catch is preferable. The formula to predict total IRF catch is:

$$C_T = g\,G, \qquad (4.6)$$

where g = ratio defined in (4.2), and G = total retained catch (t) of the target species (from DMP landings). Continuing the above example, yelloweye rockfish are caught at a rate of 23.0 kg/t halibut in the QCI halibut longline fishery (Table 7). If the DMP landings of halibut were 3,000 t then the predicted total removals of yelloweye rockfish would be C_T = 23.0 kg/t × 3,000 t = 69 t. Again, simply using the 95% confidence interval for g of 20.5-25.9 kg/t yields a range of 61.5-77.7 t; however, the confidence profile is specific to g, not to C_T.

5. Simulated observer coverage

To simulate observer coverage, we follow the principles of sampling finite populations. Appendix A summarizes the fundamental results of sampling theory presented by Thompson (1992). Given the 14 populations of observer logs (Table 6), we simulate various levels of observer coverage (5, 10, 15,..., 95%). For each level of coverage, we perform 500 random trials without replacement (i.e., observers do not observe a set more than once). Each trial produces a sampled catch that must be extrapolated to estimate total catch. This can be done in two ways.

The first and most simple method, called simple random sampling, is to scale the sampled catch up by the amount of observer coverage (Appendix A, Table A1):

$$\hat{C} = \frac{N}{n}\sum_{i=1}^{n} C_i \;, \qquad (5.1)$$

where N = total number of sets, n = number of sampled sets, and C_i = observed catch in set i ($i = 1,...,n$). For example, if the sampled catch is 10 fish and the observer coverage n/N is 10%, then the estimate of total catch is $\hat{C} = (1/0.1)\times 10 = 100$ fish.

Alternatively, we can include a covariate of catch to help us predict total catch (Appendix A, Table A2). The most obvious is a measure of effort like soak time or number of hooks. Subsequently, a sampled catch per unit effort gives us a rate that can be applied against the total effort to predict total catch. We explore this option, called the ratio method, using pieces/hook for longline and handline gear and pieces/hour for troll gear. Consider a population of N sets, with catch C_i and effort E_i in set i ($i = 1,...,N$). Suppose that efforts are known for all sets, but the catches are observed only for a sample of size $n < N$. Then the total

catch $C = \sum_{i=1}^{N} C_i$ can be estimated as

$$\hat{C}_r = \hat{\rho}\, E, \tag{5.2}$$

where $E = \sum_{i=1}^{N} E_i$ is the total effort and

$$\hat{\rho} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} E_i}. \tag{5.3}$$

As $n \to N$, $\hat{C}_r \to C$. This limiting property would not be valid for the alternative catch rate estimate:

$$\hat{\rho}' = \frac{1}{n} \sum_{i=1}^{n} \frac{C_i}{E_i}. \tag{5.4}$$

Because we are sampling known observer populations, we are survey sampling finite populations. Further, the chosen observer coverage levels produce sample sizes that are ≥ 5% of the total population sizes. An individual sample is consequently subject to a variance adjustment called the *finite population correction* (Thompson 1992):

$$FPC = \frac{N-n}{N} = 1 - \frac{n}{N}, \tag{5.5}$$

where n = sample size and N = population size. If the population N is large in relation to n, then $FPC \to 1$ and there is no variance reduction. However, when sampling small populations, the $FPC \to 0$ and the variance is reduced. Obviously, when $n = N$, the variance will be 0.

If we resample the population using M ($j = 1,\ldots,M$) trials, we get an empirical distribution of total catch estimates $\hat{C}_j$ for each level of coverage (Fig. 4). The lower the coverage, the less likely we can accurately estimate the true catch. Both methods (simple random sampling: $\hat{C} = \hat{\tau}$ (A1.3), ratio method: $\hat{C}_r = \hat{\tau}_r$ (A2.5)) produce similar results. There is some visual evidence that introducing the effort covariate actually increases the variability of predictions, but the differences are so slight that we use the former method (simple random sampling, Table A1) from this point forward.

The variability of $\hat{C}_j$ inherently reflects the variance-reducing effects of sample sizes that approach the population size. We can therefore calculate the coefficient of variation as the ratio of the standard deviation of $\hat{C}_j$ to the mean of $\hat{C}_j$ for each level of coverage:

$$(5.6) \qquad CV = \frac{\sqrt{\frac{1}{M-1}\sum_{j=1}^{M}(\hat{C}_j - \bar{\hat{C}})^2}}{\frac{1}{M}\sum_{j=1}^{M}\hat{C}_j}.$$

We can compare the CV in (5.6) with that calculated from the variance derived using the finite population correction (Eqns. 5.5, A1.5):

$$(5.7) \qquad CV = \frac{1}{M}\sum_{j=1}^{M}\frac{\sqrt{\hat{V}[\hat{C}_j]}}{\hat{C}_j}.$$

The CV is a useful and standard measure for making decisions. For example, a CV of 10% means that managers will know the true catch ± 20%, 95% of the time.

Boxplots of estimated catch (Figs. 5-18) show the distribution of predicted catch in relation to the true catch (horizontal red line). Not surprisingly, at lower observer coverage the true catch is less accurately approximated. It appears to be generally true for all rockfish species that lower coverage underestimates the true catch. Higher proportions of zero-catch p exaggerate this effect.

For illustrative purposes, we examine the QCI halibut longline fishery (Fig. 5) in which observers recorded information on 2,018 sets (267 sets at 0-100 m, 728 sets at 101-200 m, 389 sets at 201-300 m, and 634 sets at 301 m or deeper). The proportion of sets that caught no yelloweye rockfish (Fig. 5A) was p = (0.22, 0.54, 0.80, 0.98) in each depth stratum, respectively. The precision curve (Fig. 5A, lower panel), described by the CV of estimated catch, indicates that ~30% observer coverage is needed to attain a CV of 10%. Quillback rockfish (Fig. 5B) had a higher probability of being absent in the sets, p = (0.61, 0.80, 1, 1), and the catch was more variable. Hence, the observer coverage necessary to attain a CV of 10% is ~55%. Even more extreme is copper rockfish (Fig. 5C) which was virtually absent from all sets, p = (0.99, 1, 1, 1). Observer coverage for such a rarely caught species would need to be >95% before achieving a CV of 10%.

The halibut longline fisheries in QCI, CC, and WCVI have been well-sampled relative to the other regional fisheries. Subsequently, the CVs in the other fisheries exhibit erratic patterns and predict much higher levels of observer coverage. We re-state that many of the observer populations used are too small to accurately represent the true population of captured IRF species.

Using the CVs calculated in (5.6), we fit a loess curve, assuming that the coverage is dependent on the CV. The model is then used to predict the observer coverage necessary to achieve a set of target CVs (Tables 11-14). The SPlus routine **predict** (Mathsoft 1999) provides interpolations but does not extrapolate beyond the CVs observed in Figs. 5-18. The prediction of observer coverage necessary to achieve various target CVs is generally dependent on the fishery and the species. If we choose a target CV of 10%, we quickly see that the coverage required in nearly all the fisheries is ~80-90%. The QCI halibut longline fishery (Table 11) suggests lower

values, but the coverage level varies widely depending on species. If we were to focus on yelloweye rockfish, we might conclude that 30% observer coverage is sufficient in the QCI halibut longline fishery. However, this level would not give us the same degree of precision for any other IRF species except perhaps silvergray rockfish (Table 11, Fig. 5G). It is almost a certainty that levels less than 100% will give us highly biased estimates of rarely caught species like china rockfish (Fig. 5D).

The numbers of observed sets by fishing year indicate very low levels of observer coverage for the ZN fishery (Table 15). At the time of writing, we were not able to get the total number of sets from the halibut fishery. Without knowing the total units (sets in this case), coverage levels are unknown. To evaluate estimates of total catch from observed catch, we compare them to the DMP landed catches which provide the minimum, known removals. Our estimates are in pieces while DMP catches are in weight. Therefore, we need to convert the estimates from pieces to weight. Ideally, directed research would determine appropriate conversion factors. In lieu thereof, we use the observer logs to approximate the mean weight of each IRF species for each of the 14 regional fisheries (Table 16). These conversions should closely reflect the knowledge and expertise of the observer culture.

We use the 2001/02 ZN longline fishery to illustrate the methodology of estimating total catch from observer catch. The procedure could be applied to the halibut fishery once coverage levels are known. The observed catch is scaled up using the coverage ratio n/N (Table 15) to derive total catch estimates (Table 17). These are converted to weight using the observer conversion factors (Table 16). For each regional fishery the coverage levels n/N can be used to simulate appropriate CVs (Table A.1, Eqn. 5.6) and derive 95% confidence limits. We constrain the lower confidence limit to 0.

The total catch estimated from observed catch (Table 17) for the ZN longline fishery is neither accurate nor precise. While the 95% confidence intervals generally include the DMP catches, the high CVs stemming from low levels of coverage make these intervals enormous. Even more concerning is the total failure of observed records to capture some of the most important species. Rougheye rockfish is the dominant species by far in the QCI ZN longline fishery (~212 t in 2001) and yet the observer logs never once recorded a catch of this species in 2001. An observed catch of 0 fish extrapolates to a total catch of 0 fish, a prediction that is obviously absurd. While the methodology is sound in principle, the limited availability of data and the low levels of observer coverage lead to highly biased estimates of total catch with precision intervals that provide no useful guidance in determining total IRF removals.

6. Discussion

The current status of observer programs on Canada's west coast is detailed in Appendix B. The partial coverage targets are based on days of fishing and aim for 10-15% coverage. Given that these programs have been implemented without input from science, DFO requested advise on two main issues: (i) estimation of total IRF catch and (ii) accuracy and precision of catch estimates at various levels of observer coverage (Appendix C).

Estimating total IRF catch can be addressed in a variety of ways. Already in place is a dockside monitoring program that measures fairly accurately the trip landings of IRF species.

This provides a minimum estimate of total IRF removals from the ecosystem. A second source of catch information is contained in fisher logs. These logs record the most detailed information on catch composition at the set level. However, for a variety of reasons – no estimates of discards, incompleteness, unavailability to DFO – they are not sufficient to determine total removals. This suggests that observer coverage is needed. Implementing 100% observer coverage is the most direct solution. It works well for the IVQ trawl fishery, but it's expensive and perhaps not feasible for the smaller vessels of the H&L fleet. Under partial coverage, there is information on total IRF removals for select sets. Using this representation, we can estimate (through extrapolation or prediction) the total IRF removals by the entire H&L fleet. We outline three possible methodologies for estimating total IRF catch from partial observer coverage.

The first method uses species-specific discard rates to adjust the DMP landed catches. In deriving discard rates, we are essentially simplifying the discard behaviour of fishermen. Our analysis shows that individual discard rates are not distributed normally. Three decisions are made: keep all the IRF, throw them all away, or high-grade. Even this simplification is not equally true for all fisheries. It certainly characterises the halibut fishery where many of the license holders have concurrent ZN licenses. In the ZN fishery, discarding and high-grading are minimised, or perhaps de-emphasised when observers are present. In the Schedule II fishery, IRF species are either kept or discarded, with no tendency to high-grade. The point is that discard behaviour is not so easily summarized by one number. We have chosen to represent it by total discarded weight over total catch weight, and provided confidence limits using bootstrap simulations.

A second method is prediction of total IRF catch from the landed catch of a fishery's target species. The bycatch prediction algorithm (4.2, 4.6) is not sophisticated. Implicit in this method is that the observed ratio somehow fully characterises the relationship between IRF species and the target. As for the discard rate, we are distilling fishermen's treatment of bycatch into one number. Both methods – discard and bycatch – deserve more serious thought. Analysis of potential influencing factors (e.g., license options, location, etc.) can highlight fishery-specific relationships. For example, Walsh et al. (2002) used a generalised additive model to predict bycatch rates from observer data, and compared these to logbook bycatch rates.

The third method extrapolates the observer catch to total catch, with precision bounds from resampling. The study could have simulated only the discarded catch and added it to the known DMP landings. However, we assumed that the observer logs were to provide an independent estimate of catch. This third method also addresses the issue of precision at various coverage levels. While the target coverage might have been 10-15% (Table B.1), our definition of coverage yields levels <5% (Table 15). When we extrapolate any catch based on <5% coverage, the total catch estimate is highly biased and grossly imprecise. As coverage increases, the estimate becomes more realistic. While this is intuitively obvious, we provide the methodology that formalises it.

The simulation routine performs well in giving measures of precision from a set of observations. It is less obvious how it reflects real-life bias. We purposely use a known population of catches so that we may judge how well the estimation routine can approximate the known total catch. We assume that this population represents the fishery, realising that this representation is probably biased in some manner. This assumption can be greatly misleading given the low coverage levels. We highlighted an extreme case in the 2001 QCI ZN longline

fishery observed at 3% (Table 17). The observer sets did not capture rougheye rockfish even though this species accounted for 63% of the DMP landings of IRF. In this case, the representative population was not even close to the actual.

The decisions made by those directing the current ASOP result in a non-random allocation of observer effort in the field. For instance, if the first set within a trip is sampled, then subsequent sets within that trip are more likely to be sampled than sets not in that trip. Vessels that are too small to accommodate an observer comfortably will be observed at a different rate than larger vessels. Some license options may experience heavier observation than others for a variety of reasons. These collective decisions produce a non-random set of observer records from which we take random samples. If we knew *a priori* which of these sets were more likely to be sampled, the convergence of the median estimate on the true value would probably not be so quick (Figs. 5-18). By incorporating covariate data (Table A.2), we try to reduce variability for small increases in bias.

Other forms of bias are not measurable given the current data collection regime. It is suspected that fishermen change their discard behaviour once an observer is onboard. If this is the case then observer records accurately reflect the altered discard behaviour. However, the systemic discard behaviour remains unknown. There are no studies that adequately separate observed and non-observed discarding. Under 100% coverage, the observed discard rate becomes the true discard rate. Under partial coverage, additional information (perhaps gleaned from behavioural interviews, under-cover monitoring, etc.) might be needed to identify any observer effect.

In this paper, we have chosen a sampling scheme that stratifies regional fisheries by depth, and samples sets within those strata. However, the methods of simple random sampling can be applied to any population. The sample units do not necessarily have to be "sets" or even "trips". Given the possibility that the total number of sets may always be difficult to determine, we might alternatively define the unit of sampling to be a spatio-temporal block. As an example, if we divide the coast into 10 spatial areas and the fishing year into 12 months, there would be 120 blocks. We could randomly sample 10% of these spatio-temporal units (i.e., 100% coverage of 12 units) and extrapolate to total catch. There would still be problems with some units differing wildly from others (e.g., no one fishes off the west coast of QCI in January); however, prior likelihoods could be assigned to the units, and sampling performed accordingly.

7. Recommendations

1. **Obtain estimates of total activity.** Calculating the coverage level of a fishery means knowing the total number of units from which an observer could have sampled. For example, if coverage is at the set level, then we need to know the total number of sets. Total fishing activity can potentially be obtained from logbook data for all fisheries, including halibut.

2. **Use discard/bycatch rates with caution.** The measures of precision for discard/bycatch rates are not necessarily applicable to estimates of total catch scaled up from landed catch using those rates. However, any estimate of total catch that is greater than landed catch necessarily offers a more precautionary estimate of total removals from the ecosystem.

3. **Identify sampling constraints from current partial observer programs.** These constraints need to be evaluated to determine the effects of non-random coverage.

4. **Explore alternative analyses to better predict total removals of IRF species:**

    a) Redefine the sampling unit so that it does not depend on knowing the total fishery effort (e.g., sets, trips, hooks, etc.). One choice of unit might be a spatio-temporal block (e.g., 10 coastal areas × 12 months) that would be sampled using 100% observer coverage.

    b) For each regional fishery explore factors (e.g., time of year, vessel class, license options, etc.) using ANOVA techniques. Initially, concentrate on a data-rich situation such as the QCI halibut longline fishery. The analysis might formulate models that predict rates of discarding and ratios of bycatch to target catch. It might also suggest stratification regimes that optimise the allocation of observer coverage.

    c) Try to simulate coverage in a manner that mimics real-life coverage, taking into account the constraints outlined in Recommendation 3.

5. **Design an observer program that will give unbiased estimates of discarded catch for each IRF species in suitable spatio-temporal strata.** This will require considerable analysis similar to that suggested in Recommendation 4b, given the constraints identified in this working paper and in Recommendation 3. The observer program should not duplicate the dockside monitoring program, which measures landed catch, but complement it.

Acknowledgements

This paper is a collaborative effort of a PSARC working group formed to address the issue of at-sea observer coverage for the commercial H&L fisheries. Working group members: Barry Ackerman, Gerry Dunsmore, Carole Eros, Jeff Fargo, Rowan Haigh, Brian Krishka, Lisa Lacko, Jon Schnute, Rick Stanley, Greg Workman, Rob Wright. Additionally, two reviewers – Claudia Hand and Paul Starr – provided useful comments.

References

Haigh, R. and L. J. Richards. 1997. A relational database for hook and line rockfish logbook data. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2408: 46 p.

Mathsoft. 1999. S-Plus 2000 guide to statistics, Vol. 2. Mathsoft, Inc. Seattle, WA.

Thompson, S. K. 1992. Sampling. John Wiley & Sons, Inc., New York, NY, 343 p.

Walsh, W. A., P. Kleiber, and M. McCracken. 2002. Comparison of logbook reports of incidental blue shark catch rates by Hawaii-based longline vessels to fishery observer data by application of a generalized additive model. Fisheries Research 58: 79-94.

Yamanaka, K. L. and A. R. Kronlund. 1997. Analysis of longline logbook data for the west coast Vancouver Island yelloweye rockfish fishery. Canadian Stock Assessment Secretariat Research Document 97/134: 41 p.

Table 1. Catch estimate data sources by fishery and period, including specific database tables.

Fishery	Period	Catch Estimate Data Source	Effort Level	Database Tables
ZN	1995-2002	PacHarvHL: Official Catch	duration hooks set trip	D_Official_Catch
	1986-1994	PacHarvHL: Logbook Program	duration hooks set	B3_Fishing_Events B4_Catches
Schedule II	April 2001-2002	PacHarvHL: Official Catch	duration hooks set trip	D_Official_Catch
	1996-2002	PacHarvHL, DMP*	trip	B5_Validation_Header B6_Validation_Species B9_Aggregate_Catches
Halibut	1998-2002	PacHarvHL, DMP*	trip	B5_Validation_Header B6_Validation_Species B7_Validation_Areas
	1991-1997	Halibut DMP* access database	trip	ValLogAreaHal ValLogCatHal ValLogHdrHal_LogPages ValTripHdrHal_Trips

*Dockside Monitoring Program

Table 2. Percentage of missing logbook trip submission compared to DMP-generated trips.

Fishing Season	ZN	Schedule II
1995	25.5	0
1996	7.0	0
1997	19.0	0
1998/99	11.7	0
1999/00	4.1	0
2000/01	1.4	0
2001/02	1.0	2.3

Table 3. Management regions defined by combinations of Pacific Fishery Management areas.

Code	Region	PFM Areas
QCI	Queen Charlotte Islands	1, 2, 101, 102, 130, 142
PR	Prince Rupert	3-5, 103-105
CC	Central Coast	6-10, 106-110
WCVI	West Coast of Vancouver Island	11, 21-27, 111, 121-127
SG	Strait of Georgia	12-20, 28, 29

Table 4. Number of observer sets by gear type (longline, handline, troll) for combinations of fishery (Halibut, ZN, Schedule II), management region, and 100-m depth intervals.

Fishery	PFM Area	Depth (m)	Longline (n)	Handline (n)	Troll (n)	Total (n)
Halibut			2			2
Halibut		100	5			5
Halibut		200	8			8
Halibut		300	1			1
Halibut		400	1			1
Halibut	CC	100	123		5	128
Halibut	CC	200	71		1	72
Halibut	CC	300	57			57
Halibut	CC	400	13			13
Halibut	PR	100	49			49
Halibut	PR	200	57			57
Halibut	PR	300	14			14
Halibut	PR	400	8			8
Halibut	PR	500	1			1
Halibut	QCI		2			2
Halibut	QCI	100	284		6	290
Halibut	QCI	200	757			757
Halibut	QCI	300	407			407
Halibut	QCI	400	525			525
Halibut	QCI	500	122			122
Halibut	SG	100	21			21
Halibut	SG	200	15			15
Halibut	WCVI	100	138		1	139
Halibut	WCVI	200	306			306
Halibut	WCVI	300	352			352
Halibut	WCVI	400	92			92
Halibut	WCVI	500	7			7
Halibut	WCVI	900	1			1
ZN		100		5		5
ZN		300	1			1
ZN	CC		1			1
ZN	CC	100	85	114	5	204
ZN	CC	200	27	5		32
ZN	CC	300	4			4
ZN	PR			8		8
ZN	PR	100	57	12		69
ZN	PR	200	17			17
ZN	PR	300	4			4
ZN	QCI	100	38	19		57
ZN	QCI	200	32			32
ZN	QCI	300	147			147
ZN	QCI	400	69			69
ZN	QCI	500	3			3
ZN	QCI	800	1			1
ZN	WCVI			8		8
ZN	WCVI	100	38	33	5	76
ZN	WCVI	200	7	1		8
ZN	WCVI	300	3			3
ZN	WCVI	400	16			16
Schedule II		100	1			1
Schedule II	CC	100			9	9
Schedule II	CC	200			1	1
Schedule II	SG	100	16			16
Schedule II	WCVI	100	100	23	39	162
Schedule II	WCVI	200	29	3	28	60
Schedule II	WCVI	300			1	1
Total			**4,135**	**231**	**101**	**4,467**

Table 5. Number of observer sets by gear type (handline, troll) for combinations of fishery (ZN, Schedule II), management region, and 50-m depth intervals.

Fishery	PFM Area	Depth (m)	Handline (n)	Troll (n)	Total (n)
ZN	CC	50	75	4	79
ZN	CC	100	39	1	40
ZN	CC	150	4		4
ZN	CC	200	1		1
ZN	PR	50	7		7
ZN	PR	100	5		5
ZN	PR		8		8
ZN	QCI	50	18		18
ZN	QCI	100	1		1
ZN	WCVI	50	33		33
ZN	WCVI	100		5	5
ZN	WCVI	150	1		1
ZN	WCVI		8		8
ZN		50	3		3
ZN		100	2		2
Schedule II	CC	100		9	9
Schedule II	CC	150		1	1
Schedule II	WCVI	50		4	4
Schedule II	WCVI	100	23	35	58
Schedule II	WCVI	150	3	28	31
Schedule II	WCVI	250		1	1
Total			**231**	**88**	**319**

Table 6. The populations of observer sets defined by 14 regional fisheries (management region, fishery, and gear type). Only records with positive effort are used.

Observer Population	Fishery	Gear	Region	Depth Interval (m)	Sets (n)
1	Halibut	Longline	QCI	100	2,018
2	Halibut	Longline	PR	100	129
3	Halibut	Longline	CC	100	263
4	Halibut	Longline	WCVI	100	871
5	ZN	Longline	QCI	100	289
6	ZN	Longline	PR	100	77
7	ZN	Longline	CC	100	112
8	ZN	Longline	WCVI	100	64
9	ZN	Handline	QCI	50	19
10	ZN	Handline	PR	50	12
11	ZN	Handline	CC	50	90
12	ZN	Handline	WCVI	50	13
13	Schedule II	Longline	WCVI	100	129
14	Schedule II	Troll	WCVI	50	68

Table 7. IRF discard rates d and total catch per retained target g in the regional (QCI, PR, CC, WCVI) halibut longline fisheries. Confidence limits (95% empirical) from 500 bootstraps are given for d and g. The proportion of sets n with $d = 0$ is p (0); with $d = 1$ is p (1). Agg = IRF Aggregate.

QCI Halibut Longline					Discard Rate			Catch per Target (kg/t)		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	666	0.847	0.081	0.069	0.048	0.095	23.0	20.5	25.9
Quillback rockfish	1	274	0.697	0.204	0.264	0.177	0.378	1.6	1.4	1.9
Copper rockfish	1	4	0.250	0.750	0.697	0.231	1.000	0.0	0.0	0.0
China rockfish	2	12	1.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0
Tiger rockfish	2	57	0.807	0.158	0.187	0.088	0.316	0.1	0.1	0.1
Canary rockfish	3	178	0.871	0.090	0.061	0.031	0.109	1.6	1.2	2.2
Silvergray rockfish	3	621	0.705	0.233	0.252	0.191	0.308	6.8	5.9	7.9
Rougheye rockfish	4	816	0.793	0.156	0.130	0.092	0.175	26.0	22.0	30.1
Shortraker rockfish	4	221	0.873	0.113	0.123	0.063	0.201	2.4	2.0	2.8
Shortspine thornyhead	4	1051	0.726	0.196	0.165	0.135	0.195	5.4	4.9	5.8
Pacific ocean perch	5	56	0.768	0.196	0.114	0.049	0.207	0.1	0.1	0.2
Yellowmouth rockfish	5	170	0.782	0.176	0.147	0.083	0.238	1.5	1.0	2.0
Redstripe rockfish	5	8	0.750	0.250	0.222	0.000	0.616	0.0	0.0	0.0
Yellowtail rockfish	6	29	0.724	0.276	0.394	0.117	0.640	0.1	0.1	0.1
Black rockfish	6	7	0.857	0.143	0.236	0.000	0.620	0.0	0.0	0.0
Widow rockfish	6	9	0.889	0.111	0.202	0.000	0.541	0.0	0.0	0.0

CC Halibut Longline			Discard Rate			Catch per Target (kg/t)		
n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
170	0.747	0.047	0.148	0.082	0.244	113.7	91.2	138.5
69	0.783	0.130	0.191	0.026	0.314	3.0	2.4	3.6
4	0.750	0.250	0.332	0.000	0.832	0.1	0.1	0.2
9	0.667	0.333	0.333	0.049	0.765	0.1	0.1	0.2
17	0.765	0.235	0.114	0.014	0.328	0.6	0.4	0.8
35	0.886	0.086	0.095	0.006	0.212	1.6	1.2	2.0
66	0.682	0.303	0.253	0.137	0.372	4.0	3.4	4.8
42	0.548	0.381	0.295	0.148	0.511	4.1	2.8	5.9
16	0.688	0.313	0.490	0.138	0.762	3.2	1.9	4.9
76	0.605	0.289	0.328	0.211	0.493	5.9	4.6	7.4
1	0.000	1.000	1.000	1.000	1.000	0.0	0.0	0.0
31	0.935	0.032	0.029	0.000	0.087	1.4	0.9	2.0
0								
0								
0								
0								

PR Halibut Longline					Discard Rate			Catch per Target (kg/t)		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	29	0.862	0.138	0.020	0.004	0.069	31.2	15.6	54.4
Quillback rockfish	1	40	0.675	0.175	0.148	0.056	0.292	12.3	8.4	16.4
Copper rockfish	1	4	0.750	0.250	0.088	0.000	0.436	0.8	0.3	1.3
China rockfish	2	1	1.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0
Tiger rockfish	2	4	0.750	0.250	0.165	0.000	0.662	0.3	0.2	0.3
Canary rockfish	3	2	1.000	0.000	0.000	0.000	0.000	0.9	0.1	1.7
Silvergray rockfish	3	5	0.800	0.200	0.181	0.000	0.578	0.9	0.7	1.2
Rougheye rockfish	4	13	0.385	0.538	0.576	0.298	0.893	3.5	2.5	4.5
Shortraker rockfish	4	3	1.000	0.000	0.000	0.000	0.000	0.6	0.5	0.7
Shortspine thornyhead	4	17	0.471	0.412	0.357	0.142	0.671	2.5	1.5	3.9
Pacific ocean perch	5	0								
Yellowmouth rockfish	5	0								
Redstripe rockfish	5	0								
Yellowtail rockfish	6	1	1.000	0.000	0.000	0.000	0.000	0.1	0.1	0.1
Black rockfish	6	1	1.000	0.000	0.000	0.000	0.000	0.2	0.2	0.2
Widow rockfish	6	0								

WCVI Halibut Longline			Discard Rate			Catch per Target (kg/t)		
n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
319	0.922	0.038	0.066	0.024	0.118	22.6	17.8	28.0
75	0.800	0.187	0.132	0.051	0.234	1.7	1.3	2.2
22	0.727	0.273	0.086	0.022	0.278	0.3	0.1	0.5
20	0.600	0.400	0.328	0.112	0.654	0.1	0.1	0.1
11	1.000	0.000	0.000	0.000	0.000	0.1	0.0	0.1
72	0.917	0.069	0.025	0.005	0.065	2.4	1.5	3.4
202	0.896	0.094	0.098	0.047	0.156	3.4	3.0	3.9
131	0.907	0.056	0.167	0.042	0.314	4.6	3.4	6.3
115	0.903	0.080	0.066	0.019	0.130	6.7	5.3	8.5
369	0.729	0.133	0.134	0.097	0.176	4.7	4.0	5.3
63	0.968	0.032	0.015	0.000	0.041	0.4	0.3	0.5
178	0.831	0.101	0.148	0.068	0.240	4.3	3.6	5.0
1	1.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0
65	0.923	0.077	0.068	0.017	0.126	0.4	0.3	0.4
1	1.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0
0								

Table 8. IRF discard rates d and total catch per retained target g in the regional (QCI, PR, CC, WCVI) ZN longline fisheries. Confidence limits (95% empirical) from 500 bootstraps are given for d and g. The proportion of sets n with $d = 0$ is p (0); with $d = 1$ is p (1). Agg = IRF Aggregate.

QCI ZN Longline					Discard Rate			Catch per Target (kg/t)		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	100	0.950	0.010	0.016	0.001	0.050	22.5	15.6	29.9
Quillback rockfish	1	41	0.805	0.000	0.006	0.003	0.010	3.3	2.2	4.5
Copper rockfish	1	9	0.889	0.000	0.024	0.000	0.065	0.2	0.1	0.3
China rockfish	2	21	0.952	0.000	0.005	0.000	0.016	0.5	0.3	0.7
Tiger rockfish	2	27	1.000	0.000	0.000	0.000	0.000	0.2	0.1	0.3
Canary rockfish	3	25	1.000	0.000	0.000	0.000	0.000	1.3	0.4	2.9
Silvergray rockfish	3	111	0.991	0.009	0.006	0.000	0.027	9.9	5.9	15.2
Rougheye rockfish	4	219	0.941	0.000	0.001	0.000	0.001	945	838	1,041
Shortraker rockfish	4	53	1.000	0.000	0.000	0.000	0.000	7.2	5.7	9.1
Shortspine thornyhead	4	101	0.772	0.109	0.087	0.051	0.134	1.7	1.3	2.1
Pacific ocean perch	5	26	1.000	0.000	0.000	0.000	0.000	0.7	0.4	0.9
Yellowmouth rockfish	5	70	1.000	0.000	0.000	0.000	0.000	7.1	5.2	9.6
Redstripe rockfish	5	3	1.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0
Yellowtail rockfish	6	26	1.000	0.000	0.000	0.000	0.000	0.4	0.2	0.7
Black rockfish	6	12	1.000	0.000	0.000	0.000	0.000	0.2	0.1	0.2
Widow rockfish	6	60	1.000	0.000	0.000	0.000	0.000	1.7	0.9	2.7

CC ZN Longline			Discard Rate			Catch per Target (kg/t)		
n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
93	0.989	0.000	0.000	0.000	0.001	526.6	425.0	680.4
95	0.800	0.011	0.006	0.004	0.009	336.4	283.8	397.7
38	1.000	0.000	0.000	0.000	0.000	28.2	20.3	37.9
37	0.946	0.000	0.004	0.000	0.009	34.4	18.8	50.0
35	0.943	0.000	0.023	0.000	0.067	16.5	10.9	23.6
49	1.000	0.000	0.000	0.000	0.000	24.1	17.7	31.7
37	0.973	0.027	0.002	0.000	0.008	30.2	17.3	48.7
5	1.000	0.000	0.000	0.000	0.000	0.5	0.3	0.9
0								
2	1.000	0.000	0.000	0.000	0.000	0.2	0.1	0.4
0								
1	1.000	0.000	0.000	0.000	0.000	0.4	0.4	0.4
1	1.000	0.000	0.000	0.000	0.000	0.1	0.1	0.1
15	0.933	0.067	0.051	0.000	0.180	2.4	1.8	3.2
7	1.000	0.000	0.000	0.000	0.000	2.7	1.5	4.1
1	1.000	0.000	0.000	0.000	0.000	0.1	0.1	0.1

PR ZN Longline					Discard Rate			Catch per Target (kg/t)		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	57	1.000	0.000	0.000	0.000	0.000	643.1	423.9	905.8
Quillback rockfish	1	64	0.828	0.063	0.257	0.027	0.455	318.9	223.0	438.1
Copper rockfish	1	9	1.000	0.000	0.000	0.000	0.000	9.8	6.0	14.0
China rockfish	2	11	0.909	0.091	0.034	0.000	0.142	27.8	15.6	40.6
Tiger rockfish	2	13	1.000	0.000	0.000	0.000	0.000	22.6	15.5	30.6
Canary rockfish	3	6	1.000	0.000	0.000	0.000	0.000	22.0	11.4	31.8
Silvergray rockfish	3	15	1.000	0.000	0.000	0.000	0.000	16.3	11.4	21.9
Rougheye rockfish	4	5	1.000	0.000	0.000	0.000	0.000	3.7	2.6	5.4
Shortraker rockfish	4	0								
Shortspine thornyhead	4	5	0.800	0.200	0.713	0.000	0.960	28.5	5.4	66.7
Pacific ocean perch	5	0								
Yellowmouth rockfish	5	0								
Redstripe rockfish	5	1	1.000	0.000	0.000	0.000	0.000	0.5	0.5	0.5
Yellowtail rockfish	6	6	1.000	0.000	0.000	0.000	0.000	7.7	4.5	11.8
Black rockfish	6	1	1.000	0.000	0.000	0.000	0.000	1.4	1.4	1.4
Widow rockfish	6	1	1.000	0.000	0.000	0.000	0.000	0.9	0.9	0.9

WCVI ZN Longline			Discard Rate			Catch per Target (kg/t)		
n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
41	0.878	0.000	0.009	0.002	0.020	78.6	55.1	105.7
40	0.925	0.000	0.003	0.000	0.007	47.5	37.5	58.3
18	0.889	0.000	0.007	0.000	0.015	11.4	4.8	19.9
35	0.800	0.000	0.017	0.008	0.027	31.3	21.0	42.2
13	1.000	0.000	0.000	0.000	0.000	2.4	1.6	3.4
36	1.000	0.000	0.000	0.000	0.000	22.7	12.3	40.2
10	1.000	0.000	0.000	0.000	0.000	55.7	23.1	86.6
17	0.647	0.000	0.003	0.001	0.005	750.3	609.5	873.6
2	1.000	0.000	0.000	0.000	0.000	0.2	0.1	0.2
6	1.000	0.000	0.000	0.000	0.000	0.4	0.2	0.6
0								
3	1.000	0.000	0.000	0.000	0.000	2.2	0.5	3.1
0								
5	0.600	0.400	0.299	0.000	0.739	0.3	0.3	0.4
5	1.000	0.000	0.000	0.000	0.000	0.5	0.3	0.7
0								

Table 9. IRF discard rates d and total catch per retained target g in the regional (QCI, PR, CC, WCVI) ZN handline fisheries. Confidence limits (95% empirical) from 500 bootstraps are given for d and g. The proportion of sets n with $d = 0$ is p (0); with $d = 1$ is p (1). Agg = IRF Aggregate.

QCI ZN Handline					Discard Rate			Catch per Target (kg/t)		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	13	0.077	0.923	0.965	0.870	1.000	21,759	13,950	32,145
Quillback rockfish	1	13	0.000	1.000	1.000	1.000	1.000	4,375	3,220	5,684
Copper rockfish	1	0								
China rockfish	2	5	0.000	1.000	1.000	1.000	1.000	1,380	1,072	1,535
Tiger rockfish	2	2	0.000	1.000	1.000	1.000	1.000	845	614	1,075
Canary rockfish	3	0								
Silvergray rockfish	3	0								
Rougheye rockfish	4	0								
Shortraker rockfish	4	0								
Shortspine thornyhead	4	0								
Pacific ocean perch	5	0								
Yellowmouth rockfish	5	0								
Redstripe rockfish	5	0								
Yellowtail rockfish	6	0								
Black rockfish	6	10	0.100	0.900	0.974	0.885	1.000	8,917	4,186	14,035
Widow rockfish	6	0								

CC ZN Handline			Discard Rate			Catch per Target (kg/t)		
n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
33	1.000	0.000	0.000	0.000	0.000	462.7	197.8	815.8
79	0.797	0.025	0.018	0.010	0.027	258.0	185.1	339.3
44	0.909	0.023	0.009	0.001	0.022	120.3	81.8	165.1
45	0.956	0.000	0.005	0.000	0.015	75.0	49.4	106.8
6	1.000	0.000	0.000	0.000	0.000	4.4	2.2	7.2
26	0.962	0.038	0.004	0.000	0.014	52.1	28.1	81.1
6	1.000	0.000	0.000	0.000	0.000	4.1	2.8	5.4
0								
0								
0								
0								
0								
2	1.000	0.000	0.000	0.000	0.000	0.4	0.4	0.4
14	0.929	0.071	0.156	0.000	0.628	24.9	7.0	55.3
11	1.000	0.000	0.000	0.000	0.000	7.2	4.6	9.9
2	1.000	0.000	0.000	0.000	0.000	1.1	1.1	1.1

PR ZN Handline					Discard Rate			Catch per Target (kg/t)		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	3	1.000	0.000	0.000	0.000	0.000	123.2	46.2	277.2
Quillback rockfish	1	13	0.923	0.077	0.104	0.000	0.314	394.8	271.6	528.1
Copper rockfish	1	3	1.000	0.000	0.000	0.000	0.000	112.8	30.6	215.6
China rockfish	2	5	1.000	0.000	0.000	0.000	0.000	46.0	35.7	51.2
Tiger rockfish	2	3	1.000	0.000	0.000	0.000	0.000	71.8	46.2	87.2
Canary rockfish	3	3	1.000	0.000	0.000	0.000	0.000	30.8	15.3	46.2
Silvergray rockfish	3	4	1.000	0.000	0.000	0.000	0.000	112.9	35.6	189.9
Rougheye rockfish	4	0								
Shortraker rockfish	4	0								
Shortspine thornyhead	4	0								
Pacific ocean perch	5	0								
Yellowmouth rockfish	5	0								
Redstripe rockfish	5	0								
Yellowtail rockfish	6	5	0.800	0.200	0.090	0.000	0.373	56.4	40.9	71.9
Black rockfish	6	3	0.667	0.333	0.136	0.000	1.000	112.9	46.2	231.0
Widow rockfish	6	0								

WCVI ZN Handline			Discard Rate			Catch per Target (kg/t)		
n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
3	1.000	0.000	0.000	0.000	0.000	28.2	5.7	71.8
9	1.000	0.000	0.000	0.000	0.000	32.7	11.6	70.3
37	0.703	0.000	0.022	0.010	0.032	691.0	514.6	899.2
15	0.933	0.000	0.014	0.000	0.040	58.1	28.6	96.3
0								
2	1.000	0.000	0.000	0.000	0.000	3.7	2.9	4.5
0								
0								
0								
0								
0								
0								
0								
1	0.000	0.000	0.357	0.357	0.357	2.2	2.2	2.2
22	1.000	0.000	0.000	0.000	0.000	200.7	72.0	384.9
0								

Table 10. IRF discard rates d and total catch per retained target g in the WCVI Schedule II fisheries. Confidence limits (95% empirical) from 500 bootstraps are given for d and g. The proportion of sets n with $d = 0$ is p (0); with $d = 1$ is p (1). Agg = IRF Aggregate.

WCVI SchedII Longline					**Discard Rate**			**Catch per Target (kg/t)**		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	9	0.000	1.000	1.000	1.000	1.000	1.9	0.8	3.5
Quillback rockfish	1	25	0.000	1.000	1.000	1.000	1.000	1.5	0.7	2.6
Copper rockfish	1	22	0.000	1.000	1.000	1.000	1.000	1.5	1.0	2.1
China rockfish	2	1	0.000	1.000	1.000	1.000	1.000	0.0	0.0	0.0
Tiger rockfish	2	0								
Canary rockfish	3	19	0.000	1.000	1.000	1.000	1.000	0.5	0.3	0.8
Silvergray rockfish	3	0								
Rougheye rockfish	4	0								
Shortraker rockfish	4	0								
Shortspine thornyhead	4	0								
Pacific ocean perch	5	0								
Yellowmouth rockfish	5	0								
Redstripe rockfish	5	0								
Yellowtail rockfish	6	3	0.000	1.000	1.000	1.000	1.000	0.1	0.0	0.1
Black rockfish	6	0								
Widow rockfish	6	1	0.000	1.000	1.000	1.000	1.000	0.0	0.0	0.0

WCVI SchedII Troll					**Discard Rate**			**Catch per Target (kg/t)**		
IRF Species	Agg	n	p (0)	p (1)	d	d(.025)	d(.975)	g	g(.025)	g(.975)
Yelloweye rockfish	0	18	0.333	0.667	0.471	0.217	0.756	3.9	2.6	5.2
Quillback rockfish	1	0								
Copper rockfish	1	0								
China rockfish	2	0								
Tiger rockfish	2	0								
Canary rockfish	3	7	0.429	0.571	0.515	0.162	0.860	0.8	0.7	0.9
Silvergray rockfish	3	5	0.400	0.600	0.437	0.054	1.000	1.1	0.5	1.8
Rougheye rockfish	4	0								
Shortraker rockfish	4	0								
Shortspine thornyhead	4	0								
Pacific ocean perch	5	0								
Yellowmouth rockfish	5	0								
Redstripe rockfish	5	0								
Yellowtail rockfish	6	0								
Black rockfish	6	0								
Widow rockfish	6	0								

Table 11. Observer coverage (%) interpolated from Figs. 5-8 for various target CVs given the observer sets outlined in Table 6 for the halibut longline fisheries. Agg = IRF Aggregate.

		Target CV						
IRF	**Agg**	**100**	**75**	**50**	**25**	**10**	**5**	**2.5**
QCI Halibut Longline								
Yelloweye rockfish	0				5	30	63	87
Quillback rockfish	1			5	17	57	83	
Copper rockfish	1	30	43	64	87			
China rockfish	2	10	18	33	67	93		
Tiger rockfish	2			6	27	71	90	
Canary rockfish	3			7	26	69	89	
Silvergray rockfish	3				7	38	72	91
Rougheye rockfish	4				9	41	74	92
Shortraker rockfish	4				16	57	83	96
Shortspine thornyhead	4					13	42	74
Pacific ocean perch	5		5	10	35	75	93	
Yellowmouth rockfish	5			5	28	70	90	
Redstripe rockfish	5	14	23	40	72			
Yellowtail rockfish	6	5	12	24	58	89		
Black rockfish	6	13	22	39	71	95		
Widow rockfish	6	12	21	40	72			
PR Halibut Longline								
Yelloweye rockfish	0	8	14	28	64	90		
Quillback rockfish	1		5	11	36	77	94	
Copper rockfish	1	23	34	54	81			
China rockfish	2	50	66	80	94			
Tiger rockfish	2	18	30	50	79			
Canary rockfish	3	42	57	75	91			
Silvergray rockfish	3	19	30	51	81			
Rougheye rockfish	4	4	9	20	51	86		
Shortraker rockfish	4	22	36	56	81	95		
Shortspine thornyhead	4	6	12	21	56	86		
Yellowtail rockfish	6	50	64	79	94			
Black rockfish	6	51	65	79	93			
CC Halibut Longline								
Yelloweye rockfish	0				13	50	79	95
Quillback rockfish	1			5	22	63	86	
Copper rockfish	1	20	32	53	81			
China rockfish	2	11	20	36	68	93		
Tiger rockfish	2	5	10	22	53	87		
Canary rockfish	3		4	12	38	79	95	
Silvergray rockfish	3			6	27	69	89	
Rougheye rockfish	4		6	12	38	78	94	
Shortraker rockfish	4	6	13	27	62	91		
Shortspine thornyhead	4			4	24	65	87	
Pacific ocean perch	5	51	67	82				
Yellowmouth rockfish	5		5	14	42	82		
WCVI Halibut Longline								
Yelloweye rockfish	0			5	16	57	84	
Quillback rockfish	1			6	25	67	88	
Copper rockfish	1	6	13	27	59	89		
China rockfish	2	7	14	27	59	90		
Tiger rockfish	2	11	21	39	71	96		
Canary rockfish	3	4	8	19	49	85		
Silvergray rockfish	3				9	45	76	92
Rougheye rockfish	4		5	13	40	80	96	
Shortraker rockfish	4	5	6	16	44	82		
Shortspine thornyhead	4				5	35	68	88
Pacific ocean perch	5			8	31	73	91	
Yellowmouth rockfish	5			5	17	58	83	
Redstripe rockfish	5	49	64	80				
Yellowtail rockfish	6			5	21	66	87	
Black rockfish	6	50	65	80	93			

Table 12. Observer coverage (%) interpolated from Figs. 9-12 for various target CVs given the observer sets outlined in Table 6 for the ZN longline fisheries. Agg = IRF Aggregate.

		Target CV						
IRF	**Agg**	**100**	**75**	**50**	**25**	**10**	**5**	**2.5**
QCI ZN Longline								
Yelloweye rockfish	0			10	34	75	94	
Quillback rockfish	1		5	11	39	78	96	
Copper rockfish	1	13	23	42	73	95		
China rockfish	2		5	14	44	82		
Tiger rockfish	2		5	12	41	79	96	
Canary rockfish	3	14	24	42	74			
Silvergray rockfish	3	6	8	19	51	85		
Rougheye rockfish	4					24	58	83
Shortraker rockfish	4			7	28	71	91	
Shortspine thornyhead	4			4	20	62	86	
Pacific ocean perch	5	5	9	21	53	86		
Yellowmouth rockfish	5		5	10	33	75	92	
Redstripe rockfish	5	28	41	60	84			
Yellowtail rockfish	6	8	16	32	65	92		
Black rockfish	6	6	14	29	63	91		
Widow rockfish	6	5	9	21	53	87		
PR ZN Longline								
Yelloweye rockfish	0			5	27	71	90	
Quillback rockfish	1			6	29	72	92	
Copper rockfish	1	11	20	37	70	94		
China rockfish	2	12	21	35	69	94		
Tiger rockfish	2	5	13	28	62	91		
Canary rockfish	3	19	30	49	78			
Silvergray rockfish	3	4	8	21	52	87		
Rougheye rockfish	4	15	26	45	76			
Shortspine thornyhead	4	30	44	64	87			
Redstripe rockfish	5	49	64	80	94			
Yellowtail rockfish	6	14	23	41	74			
Black rockfish	6	48	63	79				
Widow rockfish	6	50	63	79				
CC ZN Longline								
Yelloweye rockfish	0			7	27	69	90	
Quillback rockfish	1				11	50	78	94
Copper rockfish	1	5	7	18	46	84		
China rockfish	2	5	11	24	56	88		
Tiger rockfish	2		5	14	44	81		
Canary rockfish	3		5	6	29	71	90	
Silvergray rockfish	3	5	12	26	57	89		
Rougheye rockfish	4	-4	14	35	69	89	94	
Shortspine thornyhead	4	44	58	75	92			
Yellowmouth rockfish	5	50	64	79	93			
Redstripe rockfish	5	50	64	79	94			
Yellowtail rockfish	6	7	13	28	61	89		
Black rockfish	6	18	29	49	78			
Widow rockfish	6	52	64	79				
WCVI ZN Longline								
Yelloweye rockfish	0		0	7	33	74	92	
Quillback rockfish	1				14	53	81	
Copper rockfish	1	10	19	38	70	95		
China rockfish	2		5	10	37	77	95	
Tiger rockfish	2	7	14	28	61	92		
Canary rockfish	3		7	19	45	83	94	
Silvergray rockfish	3	10	13	28	57	85	92	95
Rougheye rockfish	4				6	33	67	88
Shortraker rockfish	4	38	52	70	91			
Shortspine thornyhead	4	13	23	44	74	93		
Yellowmouth rockfish	5			33	27	46	74	84
Yellowtail rockfish	6	15	25	44	75			
Black rockfish	6	15	26	46	76			

Table 13. Observer coverage (%) interpolated from Figs. 13-16 for various target CVs given the observer sets outlined in Table 6 for the ZN handline fisheries. Agg = IRF Aggregate.

		Target CV						
IRF	**Agg**	**100**	**75**	**50**	**25**	**10**	**5**	**2.5**
QCI ZN Handline								
Yelloweye rockfish	0	4	11	25	53	86		
Quillback rockfish	1		4	13	42	76	96	
China rockfish	2	11	22	40	71	96		
Tiger rockfish	2	34	46	63	88			
Black rockfish	6	5	13	30	62	91		
PR ZN Handline								
Yelloweye rockfish	0	26	38	57	81	91	94	96
Quillback rockfish	1			22	52	83	91	94
Copper rockfish	1	49	64	79	89	94	95	96
China rockfish	2	18	28	46	77	90	94	95
Tiger rockfish	2	24	37	55	81	92	94	95
Canary rockfish	3	18	29	45	76	90	94	95
Silvergray rockfish	3	22	33	51	79	91	94	95
Yellowtail rockfish	6	13	19	35	65	87	93	95
Black rockfish	6	35	47	66	84	92	95	96
CC ZN Handline								
Yelloweye rockfish	0	8	16	34	64	92		
Quillback rockfish	1			7	27	70	90	
Copper rockfish	1		7	16	44	83		
China rockfish	2		5	12	40	79	94	
Tiger rockfish	2	18	30	49	79			
Canary rockfish	3		6	17	48	84		
Silvergray rockfish	3	12	22	38	69			
Redstripe rockfish	5	32	46	67	89			
Yellowtail rockfish	6	16	27	47	78			
Black rockfish	6	9	16	32	67	93		
Widow rockfish	6	35	49	68	90			
WCVI ZN Handline								
Yelloweye rockfish	0	31	45	65	88			
Quillback rockfish	1	31	45	65	88			
Copper rockfish	1	9	18	32	62	92		
China rockfish	2	19	29	47	78			
Canary rockfish	3	50	63	79				
Black rockfish	6	30	43	63	86			

Table 14. Observer coverage (%) interpolated from Figs. 17-18 for various target CVs given the observer sets outlined in Table 6 for the Schedule II fisheries. Agg = IRF Aggregate.

		Target CV						
IRF	**Agg**	**100**	**75**	**50**	**25**	**10**	**5**	**2.5**
WCVI SchedII Longline								
Yelloweye rockfish	0	15	26	47	77	96		
Quillback rockfish	1	6	13	27	60	89		
Copper rockfish	1	5	10	21	52	86		
China rockfish	2	51	65	80	93			
Canary rockfish	3	7	14	28	62	91		
Yellowtail rockfish	6	31	44	64	86			
Widow rockfish	6	50	64	80	94			
WCVI SchedII Troll								
Yelloweye rockfish	0	2	6	18	48	83	97	
Canary rockfish	3	9	19	36	67	92		
Silvergray rockfish	3	17	28	46	76			

Table 15. Observer coverage by fishing year: n = number of observer sets, N = number of sets in regional fishery, n/N = ratio of observer sets to fishery sets.

Observer				1999			2000			2001			2002		
Population	Fishery[1]	Gear[2]	Region	n	N	n/N	n	N	n/N	n	N	n/N	n	N	n/N
1	2	5	QCI	139			348			726			884		
2	2	5	PR	8			52			32			37		
3	2	5	CC	11			39			105			109		
4	2	5	WCVI	74			167			279			376		
5	5	5	QCI	87	1507	0.06	102	1087	0.09	31	1033	0.03	70		
6	5	5	PR	68	390	0.17		276		9	231	0.04			
7	5	5	CC	40	915	0.04	35	844	0.04	40	796	0.05			
8	5	5	WCVI		1339		16	1223	0.01	6	1944	0.00	42		
9	5	4	QCI	17	67	0.25		61		2	364	0.01			
10	5	4	PR	12	99	0.12		71		8	288	0.03			
11	5	4	CC	56	387	0.14	16	180	0.09	23	469	0.05			
12	5	4	WCVI		379			222			254		42		
13	4	5	WCVI		0					36	2796	0.01	93		
14	4	10	WCVI		0					21	526	0.04	47		

[1] 2=Halibut, 5=ZN, 4=Schedule II

[2] 5=Longline, 4=Handline, 10=Troll

Table 16. Mean weight per fish of IRF species across all years for the 14 regional fisheries from observer estimates. Final row is the mean of the table mean estimates.

Obs				Species HART code														
Popn	Fishery	Gear	Region	394	396	403	405	407	417	418	424	426	431	433	437	439	440	442	451
1	2	5	QCI	2.182	1.217	4.982	2.087	1.322	1.985	1.692	1.054	1.919	1.064	1.364	2.108	0.970	1.574	2.849	0.896
2	2	5	PR	2.900		4.082	2.752	1.534		1.361	1.198	3.629	0.907	1.368	0.907			3.533	1.283
3	2	5	CC	2.398	1.400	7.644	2.182	0.905			1.122		0.777	1.526	2.000		1.415	3.048	1.102
4	2	5	WCVI	2.680	1.135	7.333	2.196	1.218		1.589	1.277	1.800	0.709	1.116	1.896	0.900	1.508	2.713	1.006
5	5	5	QCI	2.159	1.490	5.857	2.177	1.280	1.733	1.367	0.924	1.000	0.756	1.010	1.423	0.983	1.794	2.848	0.982
6	5	5	PR	0.859			1.474	0.984	1.814	1.660	0.875	2.720	0.800	1.250	0.936	0.900		2.395	1.133
7	5	5	CC	0.541			1.891	0.833	0.907	0.633	0.917	1.260	0.646	1.042	1.283	0.907	1.361	2.654	0.338
8	5	5	WCVI	1.897		1.357	2.424	1.483		1.001	1.260	1.415	0.846	1.277	1.269		1.738	2.426	0.612
9	5	4	QCI								1.183	2.175	0.904	2.490				3.277	
10	5	4	PR				1.133	0.755		0.997	0.991	1.510	0.813	1.284	0.906			2.268	
11	5	4	CC				1.660	0.902	1.020	0.746	0.880	1.063	0.607	1.106	1.199	0.452		3.234	
12	5	4	WCVI					0.670		0.700	0.768	0.809	0.707		1.150			1.400	
13	4	5	WCVI					1.433	1.400	1.133	0.912		0.900		1.073			1.707	
14	4	10	WCVI				2.783								2.270			3.052	
Mean				1.952	1.311	5.209	2.069	1.110	1.477	1.171	1.028	1.755	0.803	1.348	1.417	0.852	1.565	2.672	0.919

Fishery: 2=Halibut, 5=ZN, 4=Schedule II
Gear: 5=Longline, 4=Handline, 10=Troll
Species HART codes:

394	Rougheye rockfish	426	Black rockfish
396	Pacific ocean perch	431	China rockfish
403	Shortraker rockfish	433	Tiger rockfish
405	Silvergray rockfish	437	Canary rockfish
407	Copper rockfish	439	Redstripe rockfish
417	Widow rockfish	440	Yellowmouth rockfish
418	Yellowtail rockfish	442	Yelloweye rockfish
424	Quillback rockfish	451	Shortspine thornyhead

Table 17. Estimated total catch using observer data from the ZN longline fisheries. The DMP catch is included for comparison purposes.

2001 QCI ZN Longline

Agg	Hart	IRF	Species	DMP Catch (t)	Logbook Catch (pieces)	Observed Catch (pieces)	Estimated Catch (pieces)	Mean Weight (kg/fish)	Estimated Catch (t)	CV @ 3.0% Coverage	Lower 95% CL (t)	Upper 95% CL (t)
0	442		Yelloweye rockfish	36.265	11,587	345	11,496	2.848	32.736	1.055	0.000	101.823
1	424		Quillback rockfish	5.567	6,407	1,160	38,654	0.924	35.713	1.188	0.000	120.548
1	407		Copper rockfish	0.831	1,157	45	1,500	1.280	1.919	2.458	0.000	11.354
2	431		China rockfish	0.802	1,204	14	467	0.756	0.353	1.278	0.000	1.255
2	433		Tiger rockfish	0.383	321	29	966	1.010	0.976	1.296	0.000	3.506
3	437		Canary rockfish	8.145	3,622	40	1,333	1.423	1.897	2.291	0.000	10.588
3	405		Silvergray rockfish	36.946	16,075	17	566	2.177	1.233	1.418	0.000	4.731
4	394		Rougheye rockfish	212.265	137,592	0	0	2.159	0.000	0.347	0.000	0.000
4	403		Shortraker rockfish	29.679	11,289	0	0	5.857	0.000	0.898	0.000	0.000
4	451		Shortspine thornyhead	0.853	0	1	33	0.982	0.033	0.707	0.000	0.079
5	396		Pacific ocean perch	0.493	7,590	0	0	1.490	0.000	1.609	0.000	0.000
5	440		Yellowmouth rockfish	4.639	3,236	0	0	1.794	0.000	1.021	0.000	0.000
5	439		Redstripe rockfish	0.003	53	3	100	0.983	0.098	3.960	0.000	0.876
6	418		Yellowtail rockfish	0.173	135	24	800	1.367	1.093	2.060	0.000	5.595
6	426		Black rockfish	0.238	319	0	0	1.000	0.000	2.080	0.000	0.000
6	417		Widow rockfish	0.010	6	3	100	1.733	0.173	1.568	0.000	0.717

2001 PR ZN Longline

Agg	Hart	IRF	Species	DMP Catch (t)	Logbook Catch (pieces)	Observed Catch (pieces)	Estimated Catch (pieces)	Mean Weight (kg/fish)	Estimated Catch (t)	CV @ 3.0% Coverage	Lower 95% CL (t)	Upper 95% CL (t)
0	442		Yelloweye rockfish	4.559	1,369	36	924	2.395	2.213	0.692	0.000	5.276
1	424		Quillback rockfish	6.155	6,837	19	488	0.875	0.427	0.733	0.000	1.052
1	407		Copper rockfish	1.888	2,083	0	0	0.984	0.000	1.994	0.000	0.000
2	431		China rockfish	0.918	1,149	0	0	0.800	0.000	1.762	0.000	0.000
2	433		Tiger rockfish	0.330	279	0	0	1.250	0.000	1.377	0.000	0.000
3	437		Canary rockfish	1.022	571	0	0	0.936	0.000	2.767	0.000	0.000
3	405		Silvergray rockfish	0.985	539	1	26	1.474	0.038	1.285	0.000	0.135
4	394		Rougheye rockfish	0.175	22	0	0	0.859	0.000	2.267	0.000	0.000
4	403		Shortraker rockfish	0.000	0	0	0	5.209	0.000			
4	451		Shortspine thornyhead	0.000	0	0	0	1.133	0.000	3.933	0.000	0.000
5	396		Pacific ocean perch	0.000	0	0	0	1.311	0.000			
5	440		Yellowmouth rockfish	0.000	0	0	0	1.565	0.000			
5	439		Redstripe rockfish	0.001	2	0	0	0.900	0.000	4.363	0.000	0.000
6	418		Yellowtail rockfish	0.069	72	0	0	1.660	0.000	1.943	0.000	0.000
6	426		Black rockfish	0.059	43	0	0	2.720	0.000	3.594	0.000	0.000
6	417		Widow rockfish	0.000	0	1	26	1.814	0.047	5.336	0.000	0.544

2001 CC ZN Longline

Agg	Hart	IRF	Species	DMP Catch (t)	Logbook Catch (pieces)	Observed Catch (pieces)	Estimated Catch (pieces)	Mean Weight (kg/fish)	Estimated Catch (t)	CV @ 3.0% Coverage	Lower 95% CL (t)	Upper 95% CL (t)
0	442		Yelloweye rockfish	33.449	10,876	268	5,333	2.654	14.155	0.697	0.000	33.888
1	424		Quillback rockfish	28.817	32,804	870	17,313	0.917	15.871	0.446	1.712	30.031
1	407		Copper rockfish	2.766	4,474	119	2,368	0.833	1.972	1.017	0.000	5.982
2	431		China rockfish	2.562	3,684	39	776	0.646	0.501	1.334	0.000	1.838
2	433		Tiger rockfish	1.028	905	23	458	1.042	0.477	0.940	0.000	1.373
3	437		Canary rockfish	1.643	1,565	41	816	1.283	1.046	0.770	0.000	2.657
3	405		Silvergray rockfish	2.956	1,616	7	139	1.891	0.263	1.436	0.000	1.020
4	394		Rougheye rockfish	2.966	1,929	0	0	0.541	0.000	3.541	0.000	0.000
4	403		Shortraker rockfish	0.304	555	0	0	5.209	0.000			
4	451		Shortspine thornyhead	0.594	0	0	0	0.338	0.000	4.781	0.000	0.000
5	396		Pacific ocean perch	0.057	3,433	0	0	1.311	0.000			
5	440		Yellowmouth rockfish	1.088	867	0	0	1.361	0.000	5.180	0.000	0.000
5	439		Redstripe rockfish	0.032	3,108	1	20	0.907	0.018	3.828	0.000	0.156
6	418		Yellowtail rockfish	0.256	316	3	60	0.633	0.038	1.412	0.000	0.145
6	426		Black rockfish	0.301	318	2	40	1.260	0.050	2.128	0.000	0.264
6	417		Widow rockfish	0.000	0	0	0	0.907	0.000	3.894	0.000	0.000

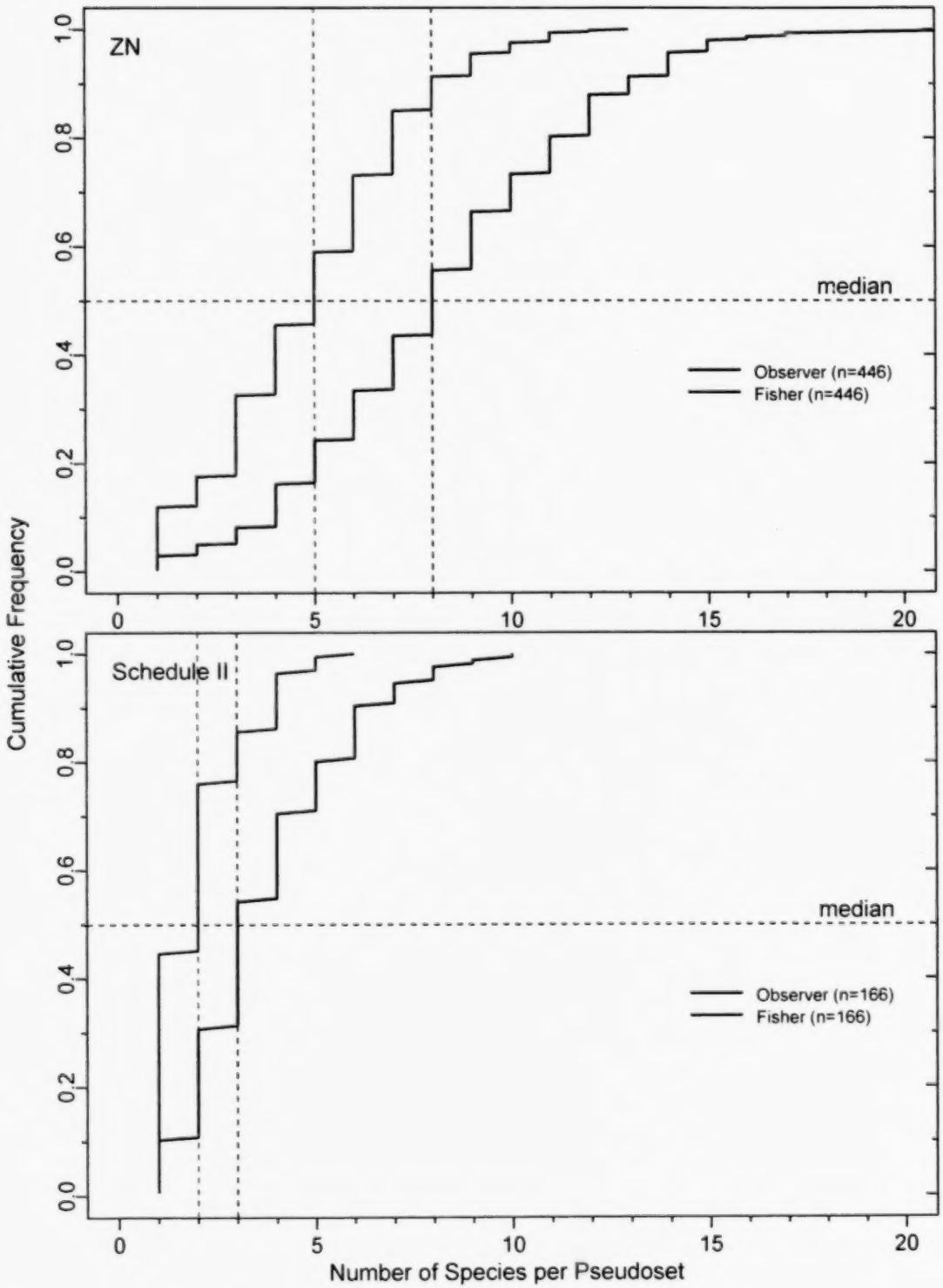

Figure 1. Cumulative frequency of number of species recorded per pseudoset – matching observer and fisher sets – by log type (observer = blue, fisher = red).

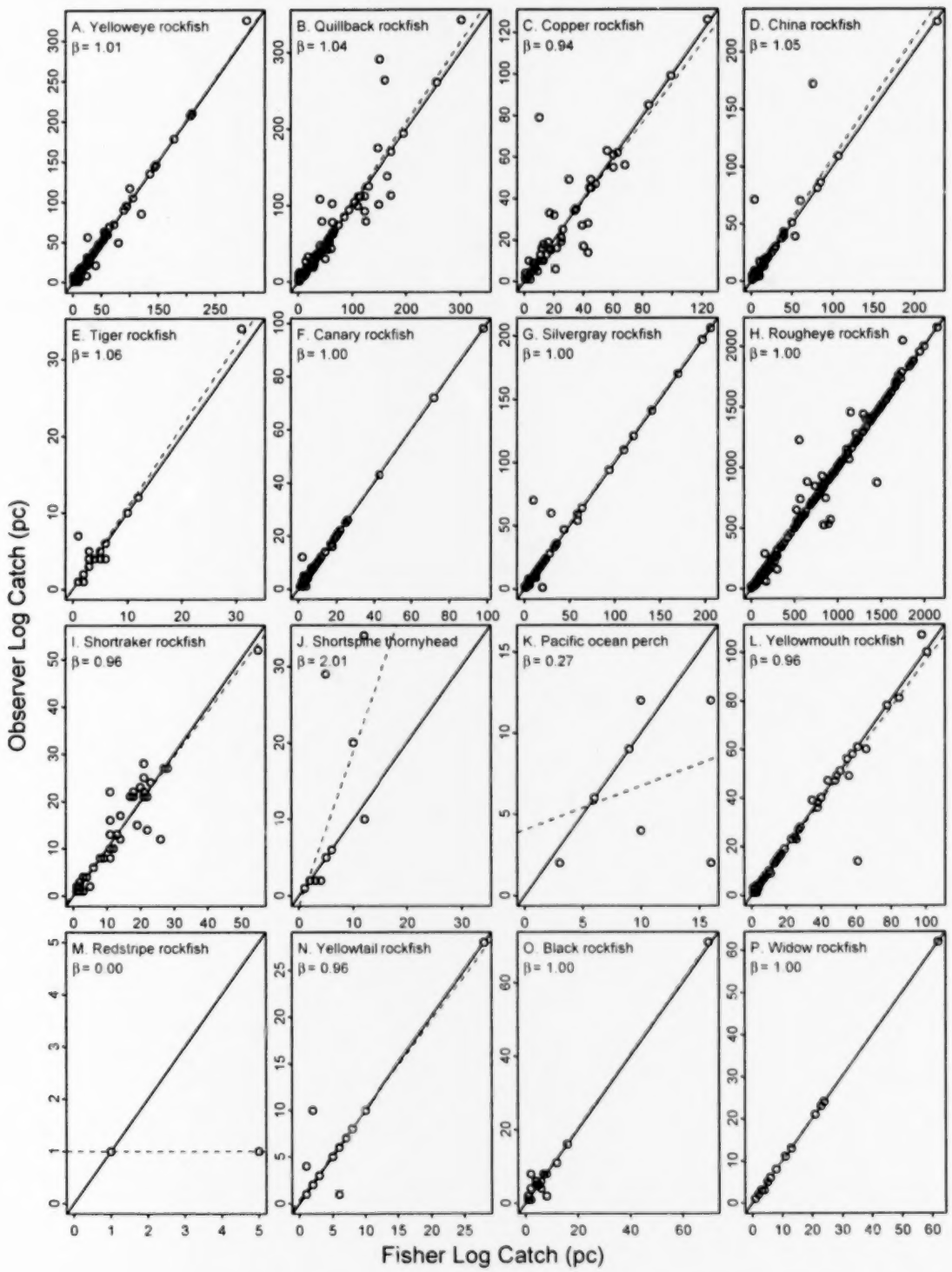

Figure 2. Comparison of total reported catch (retained + discarded pieces) between observer logs and fisher logs for the ZN and Schedule II fleets combined. Solid line indicates a 1:1 ratio. Dashed line indicates slope (β) of the regression with observer catch as the dependent variable.

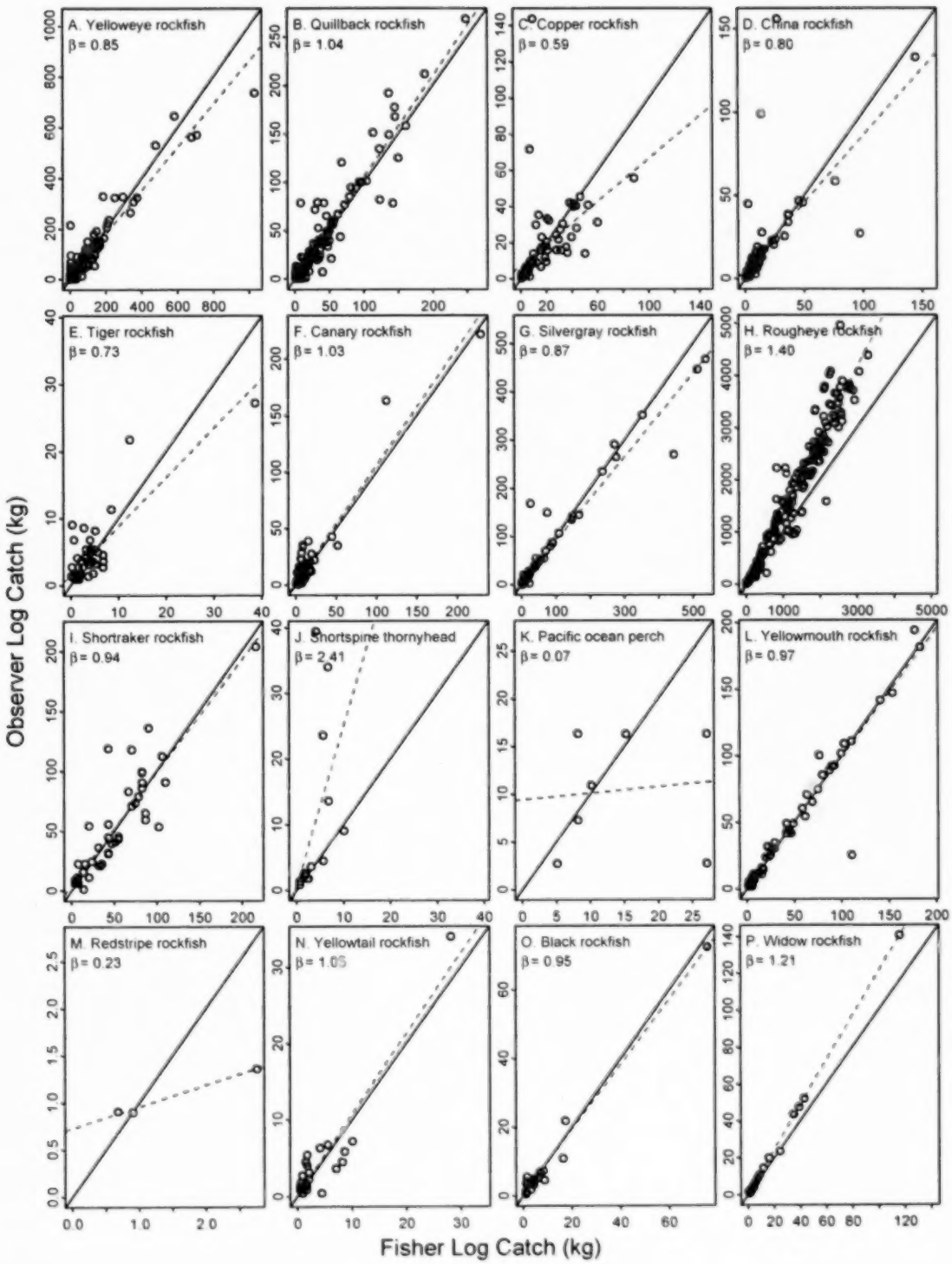

Figure 3. Comparison of total reported catch (retained + discarded weight) between observer logs and fisher logs for the ZN and Schedule II fleets combined. Solid line indicates a 1:1 ratio. Dashed line indicates slope (β) of the regression with observer catch as the dependent variable.

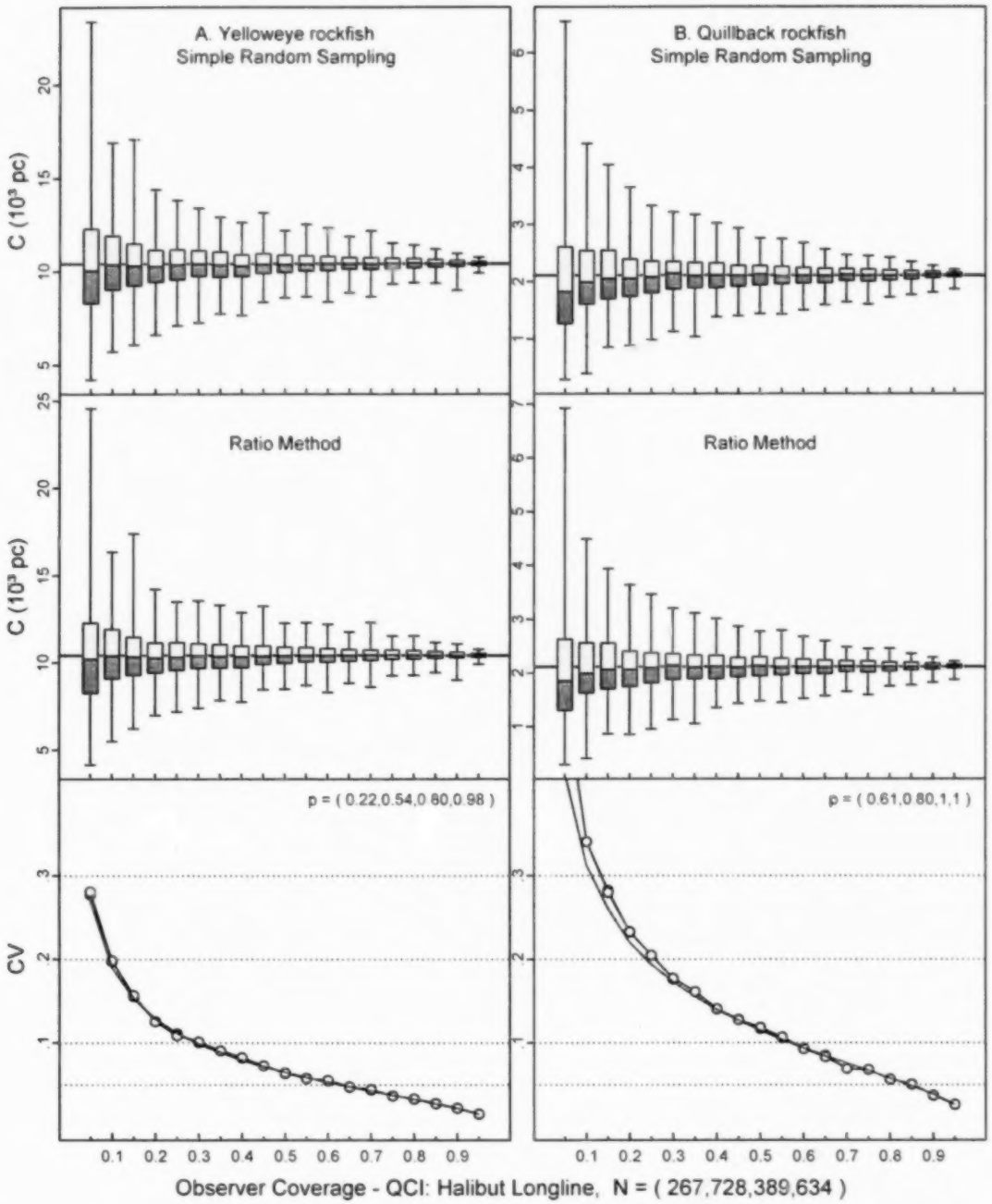

Figure 4. Comparison of catch estimates of yelloweye and quillback rockfish in observer sets from the halibut longline fishery in QCI using the two methods outlined in Appendix A, Tables A1-A2. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Top panel: $\hat{C}$, horizontal red line indicates true catch. Mid panel: $\hat{C}_r$. Bottom panel: coefficients of variation { 2 blue lines – Eqn (5.6) for $\hat{C}$, $\hat{C}_r$; 3 red lines – Eqn. (5.7) for $(\hat{C}, \hat{V}[\hat{C}])$, $(\hat{C}_r, \hat{V}[\hat{C}_r])$, and $(\hat{C}_r, \widetilde{V}[\hat{C}_r])$, Appendix A }. N = Number of sets in each depth stratum, p = proportion of N with zero catch.

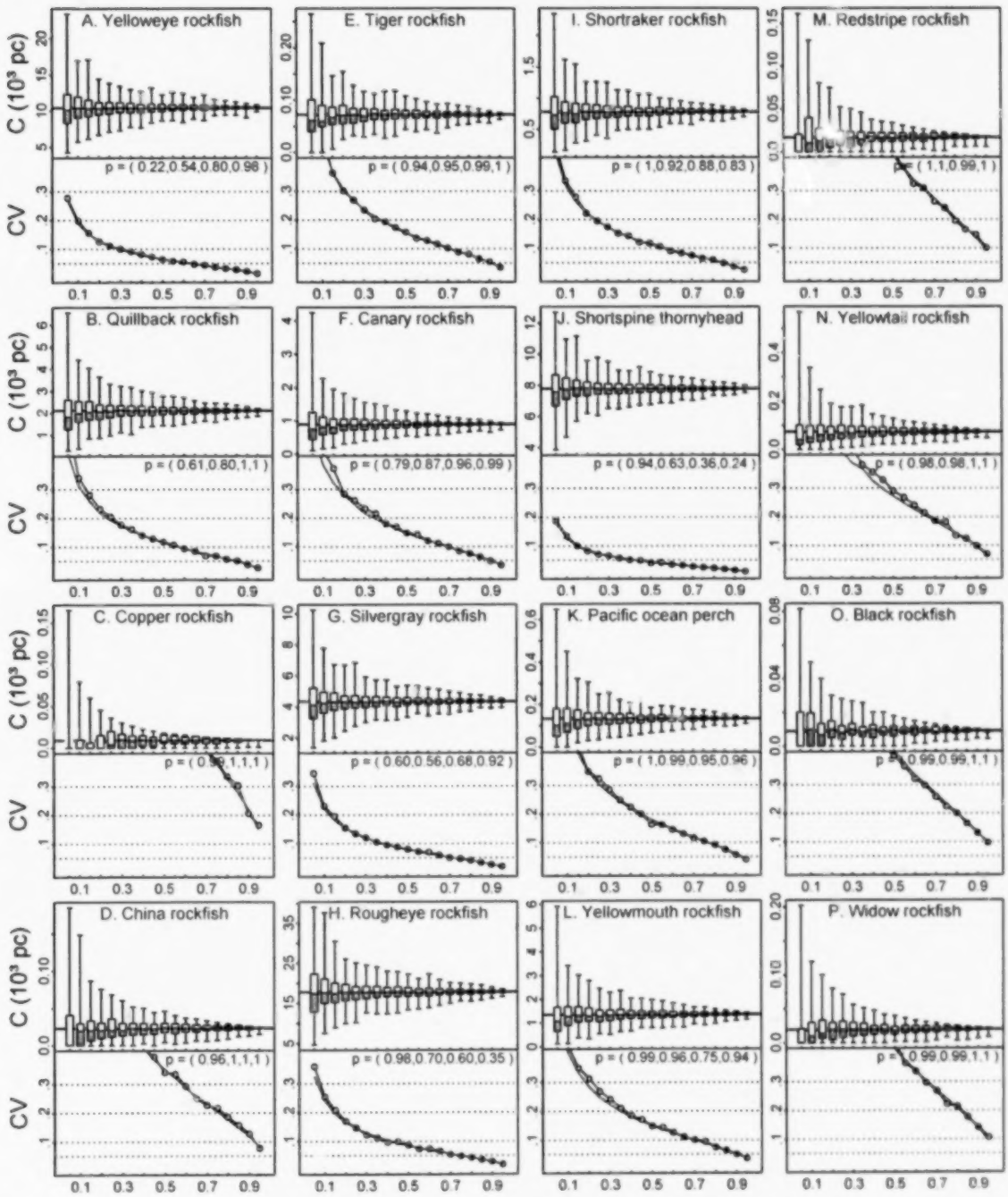

Figure 5. Halibut longline fishery in QCI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 2,018 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

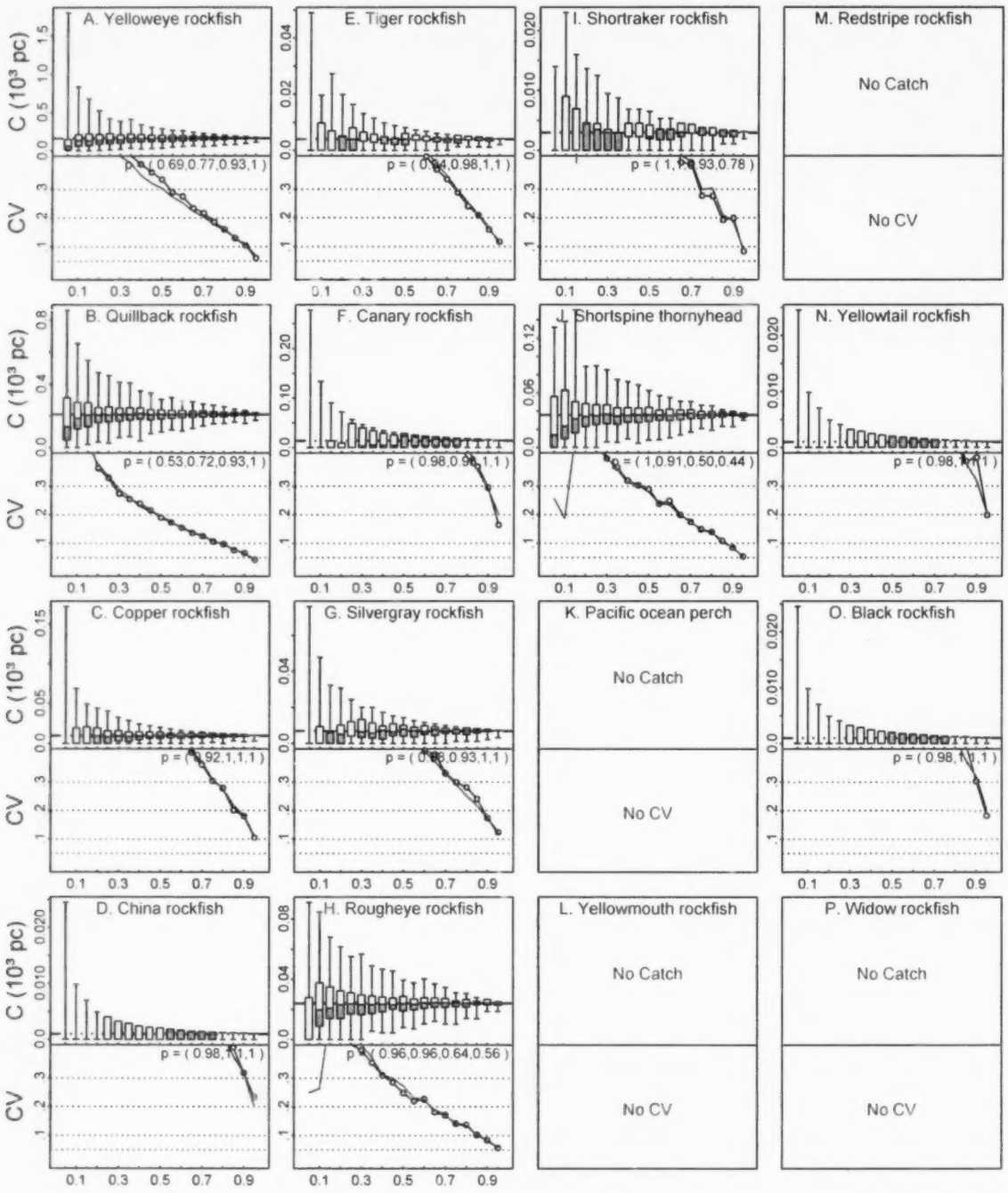

Figure 6. Halibut longline fishery in PR – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 129 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

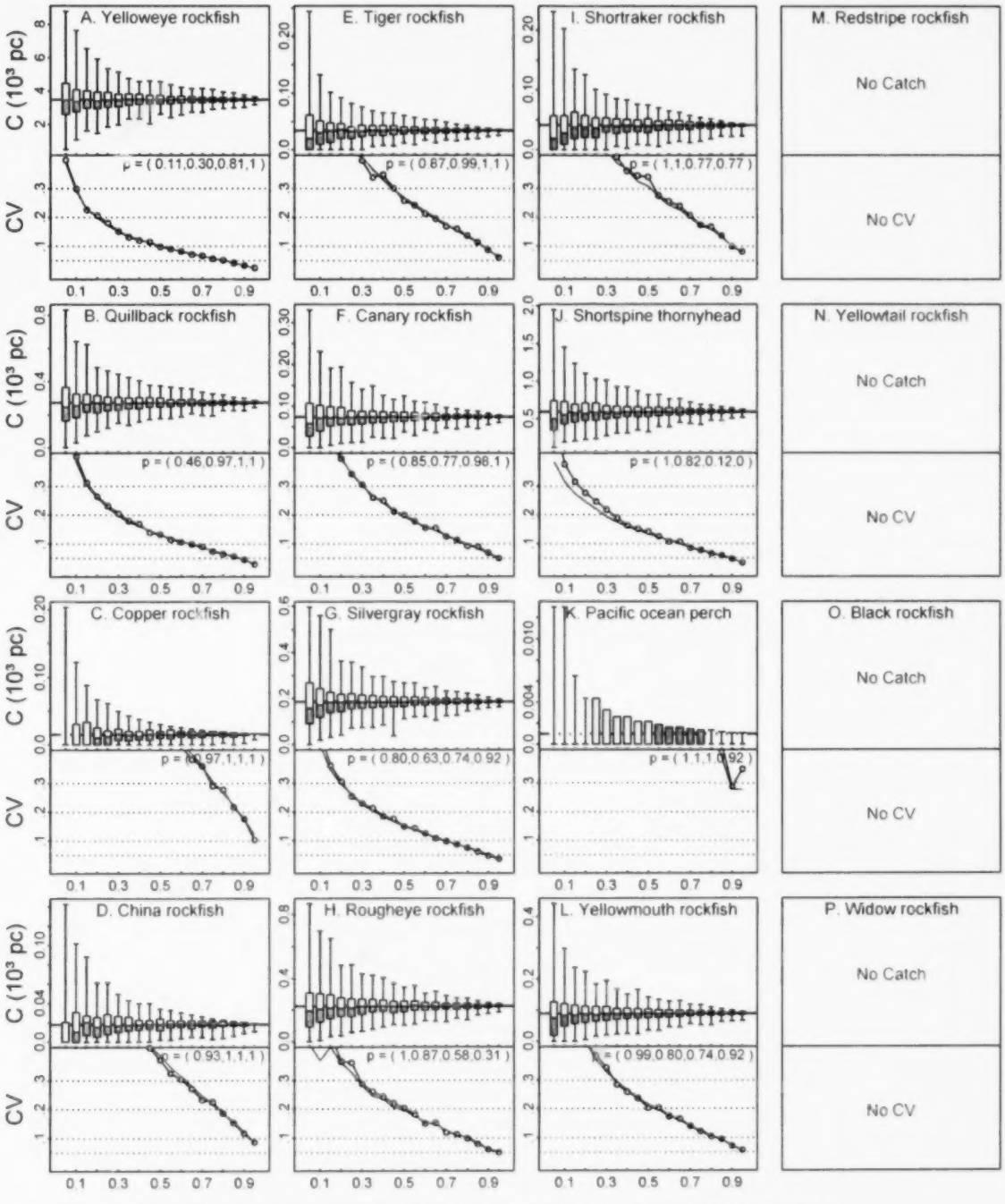

Figure 7. Halibut longline fishery in CC – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 263 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

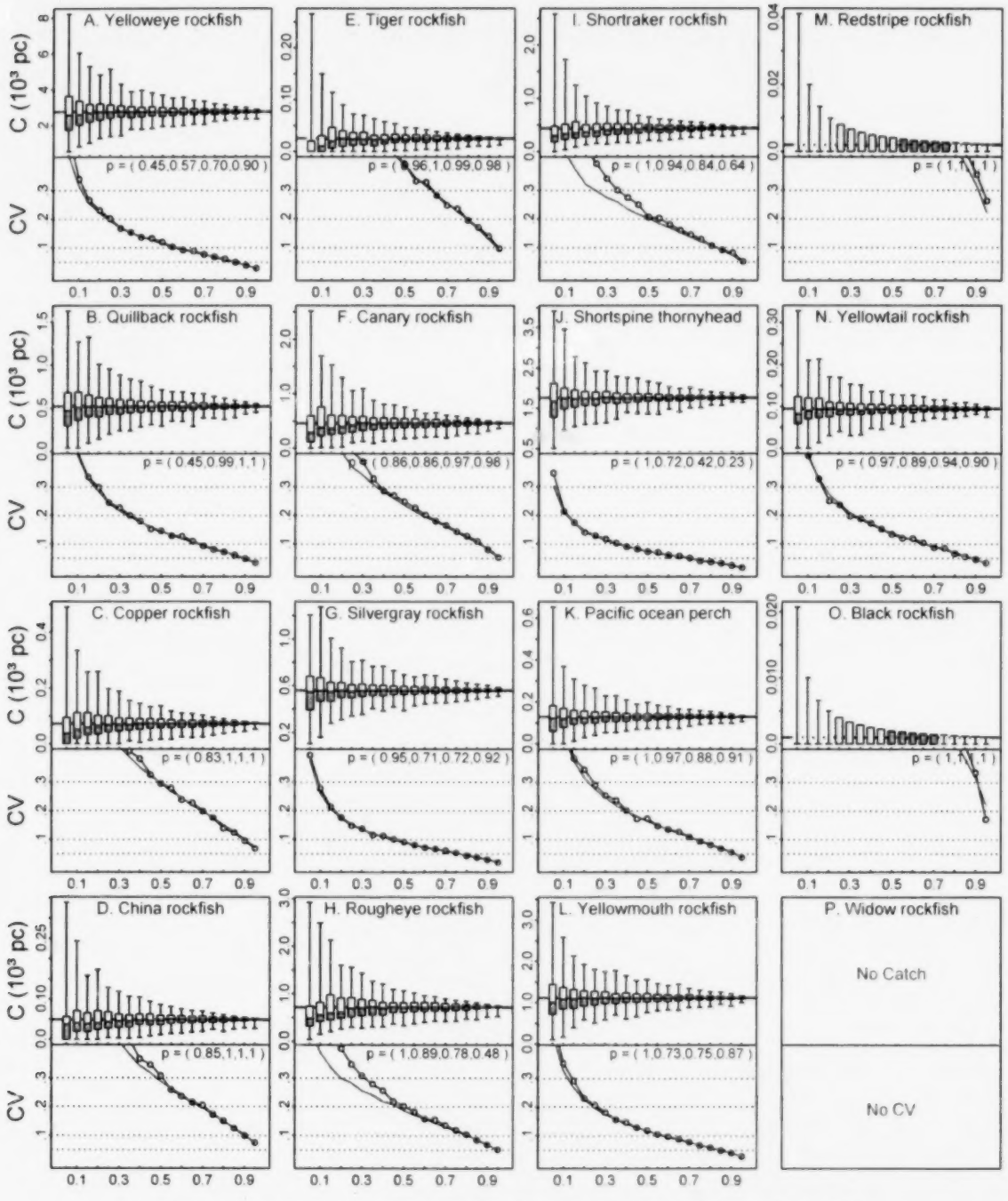

Figure 8. Halibut longline fishery in WCVI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 871 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

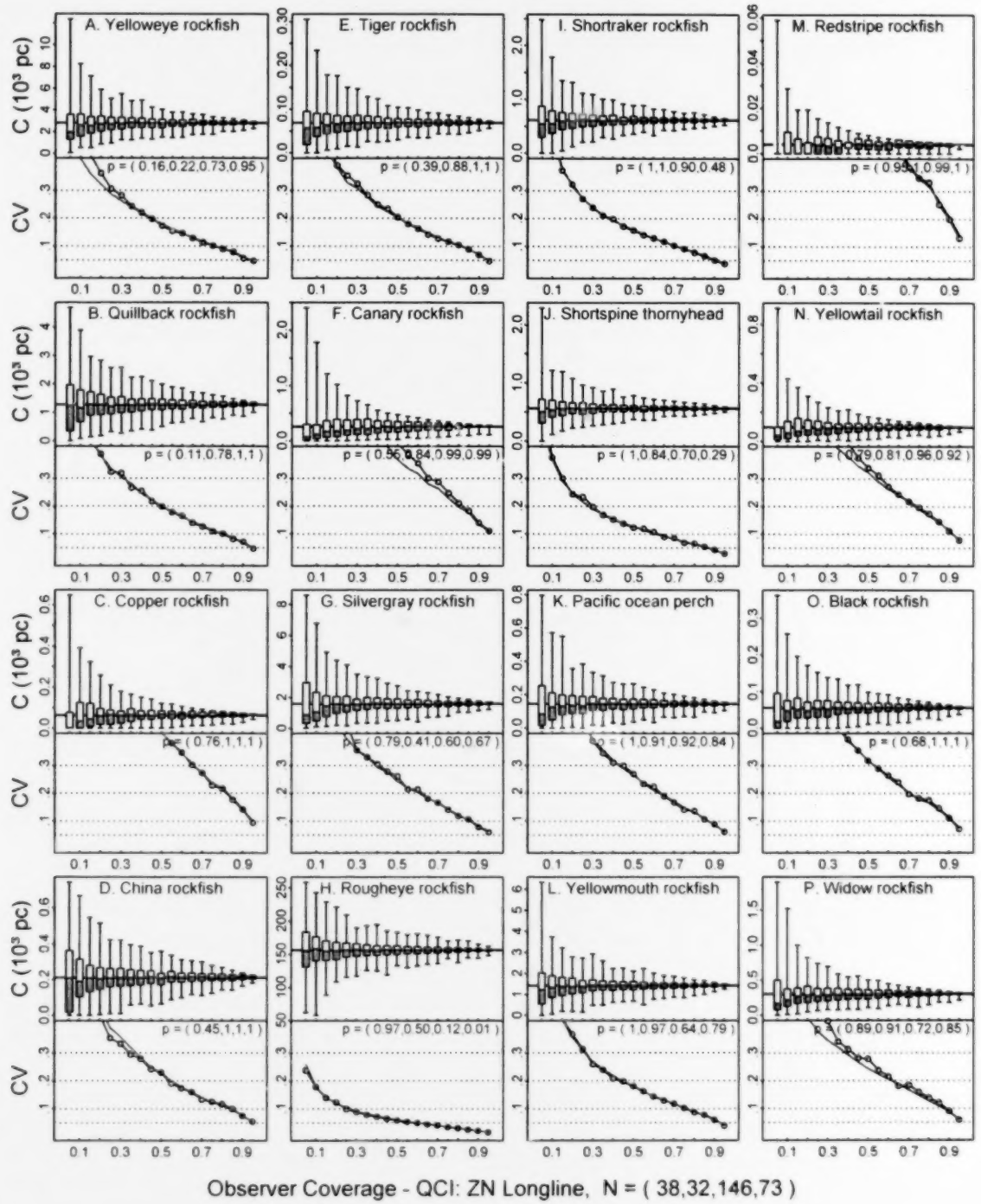

Figure 9. ZN longline fishery in QCI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 289 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

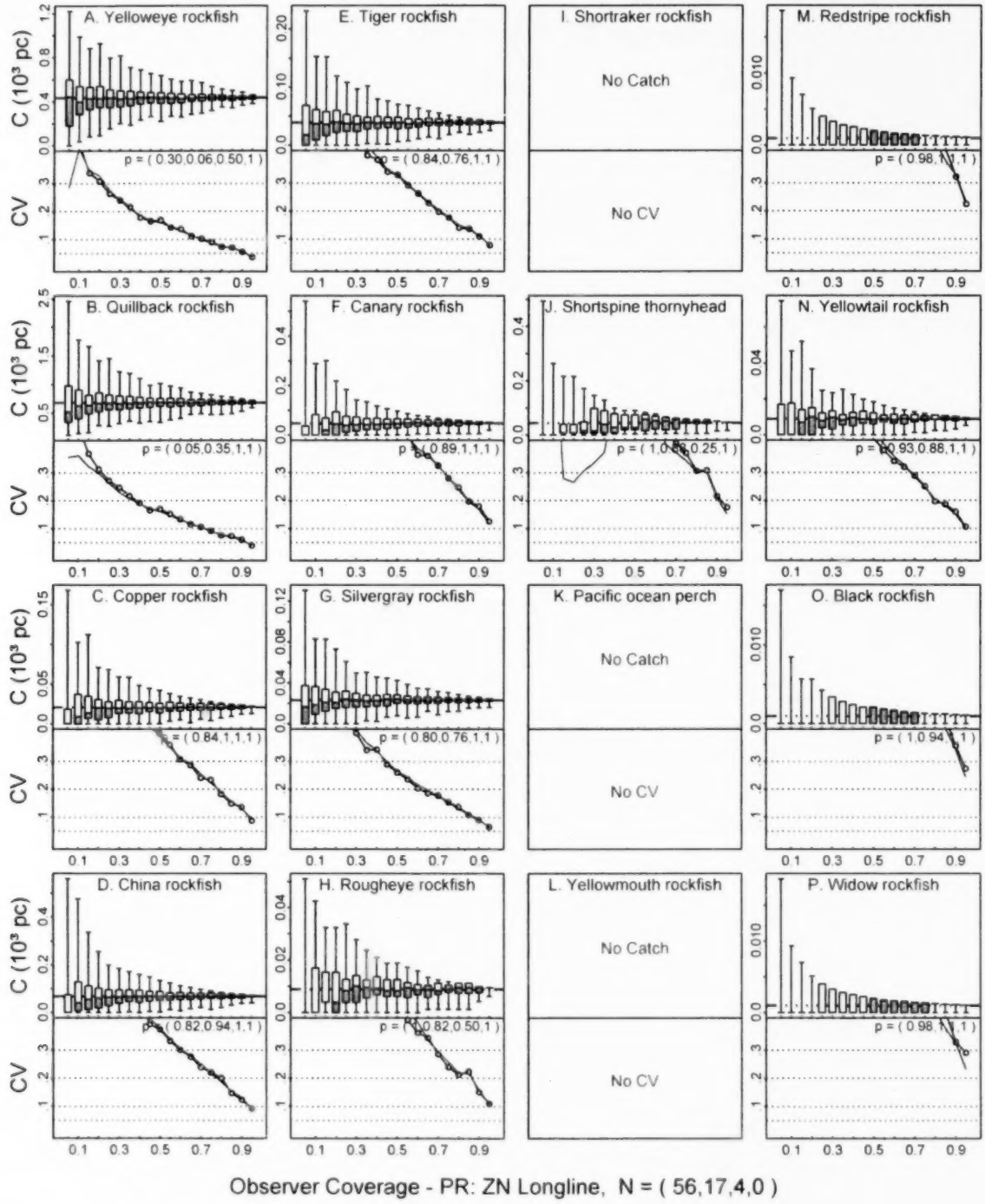

Figure 10. ZN longline fishery in PR – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 77 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

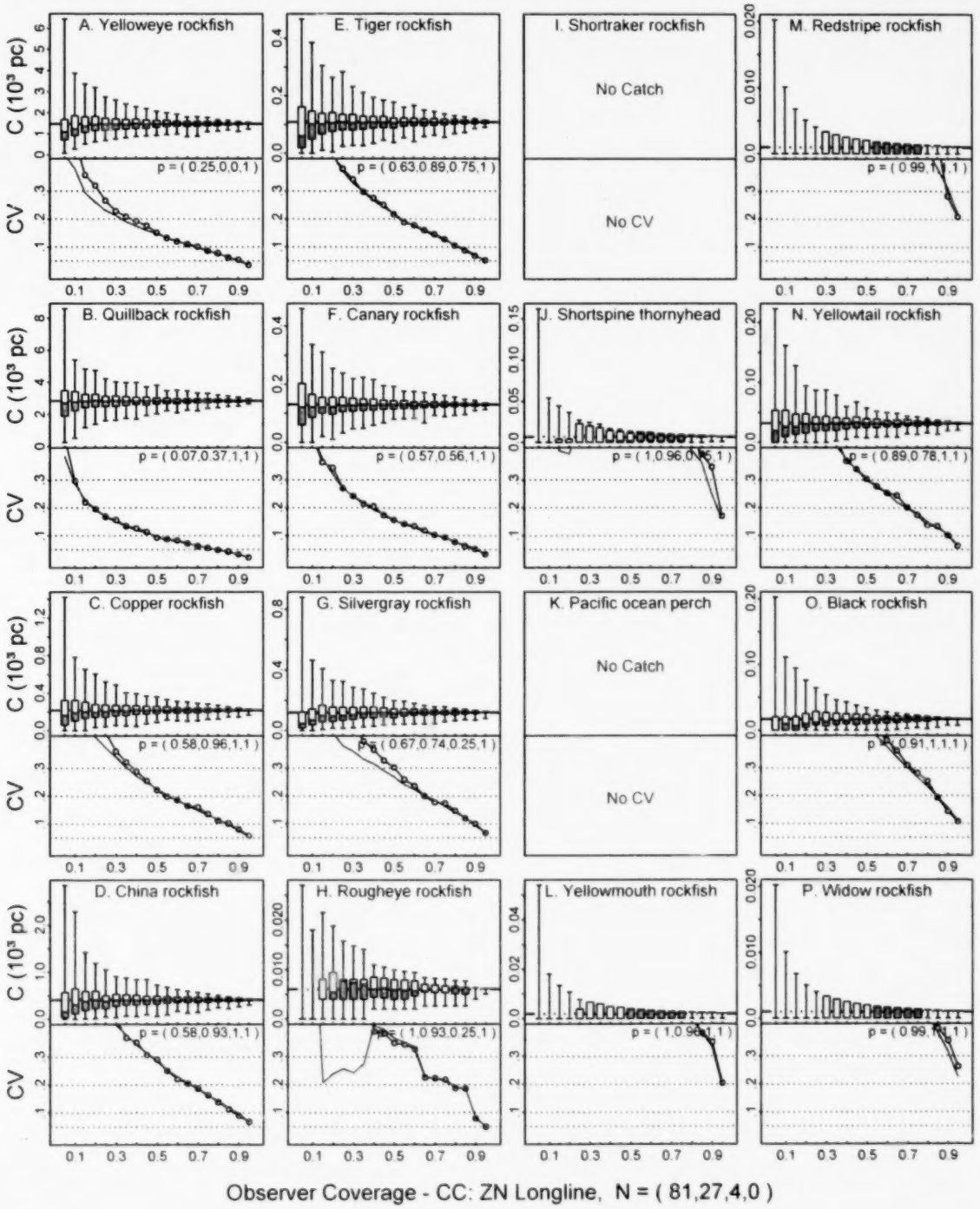

Figure 11. ZN longline fishery in CC – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 112 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

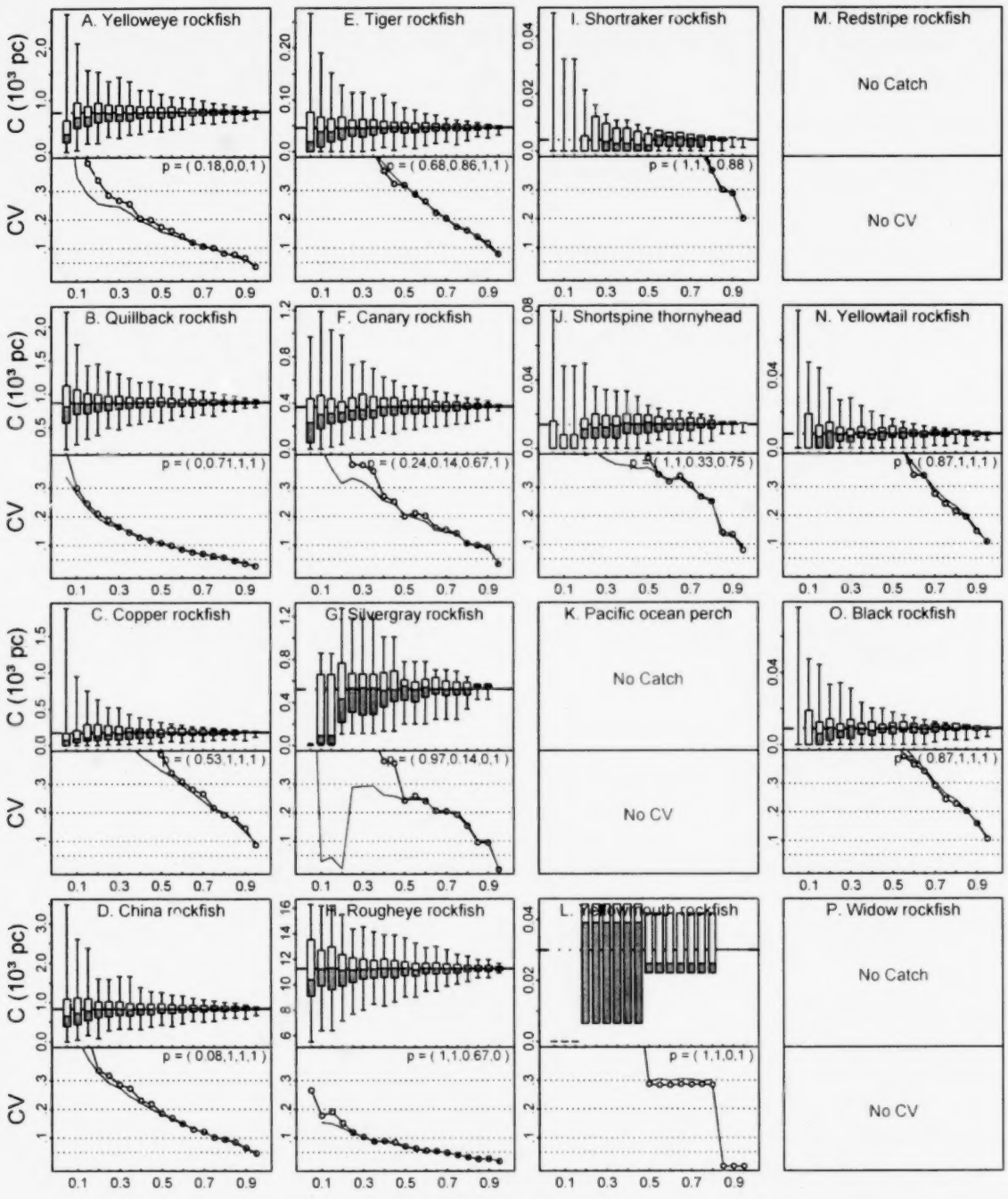

Figure 12. ZN longline fishery in WCVI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 64 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

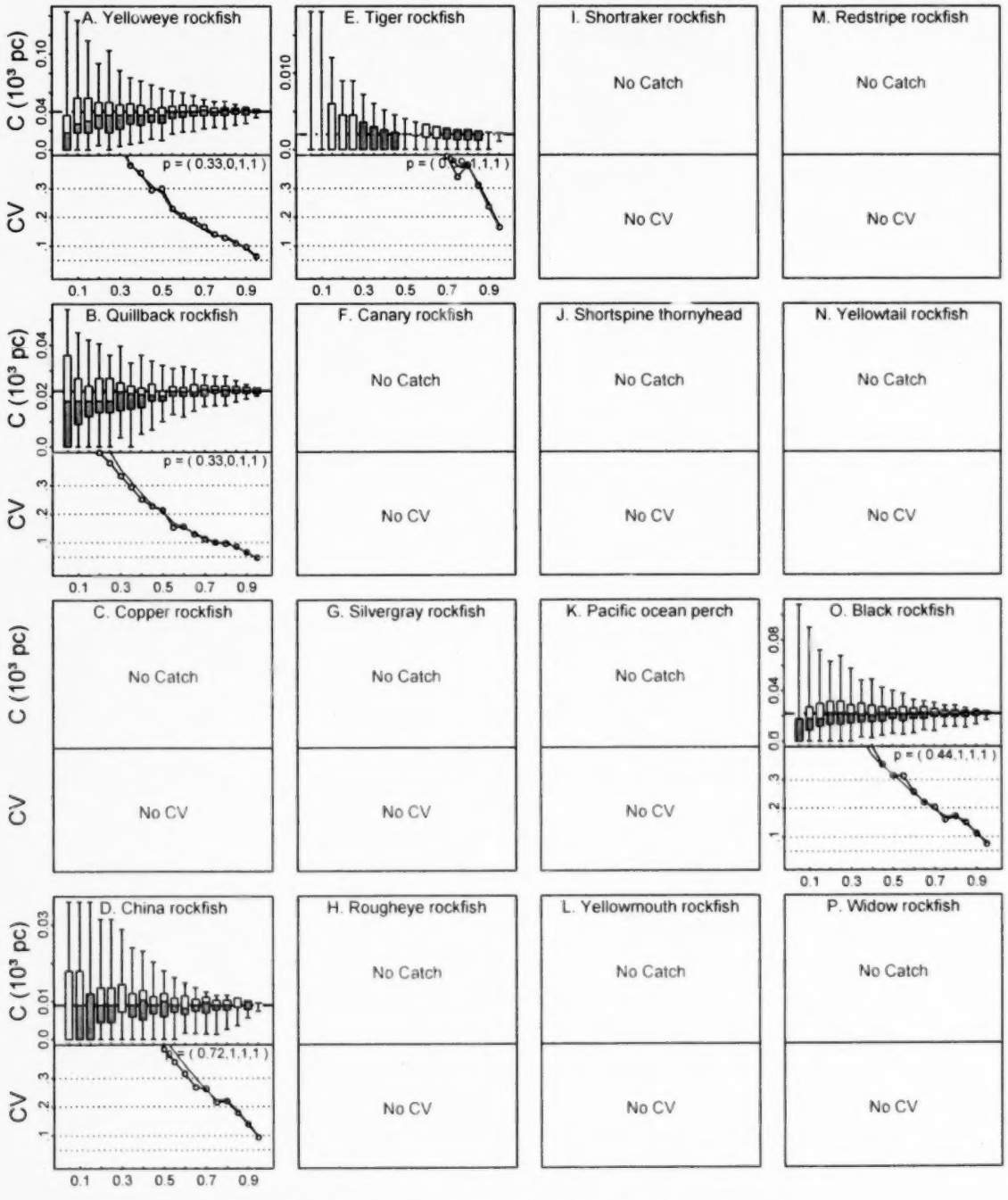

Figure 13. ZN handline fishery in QCI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 19 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

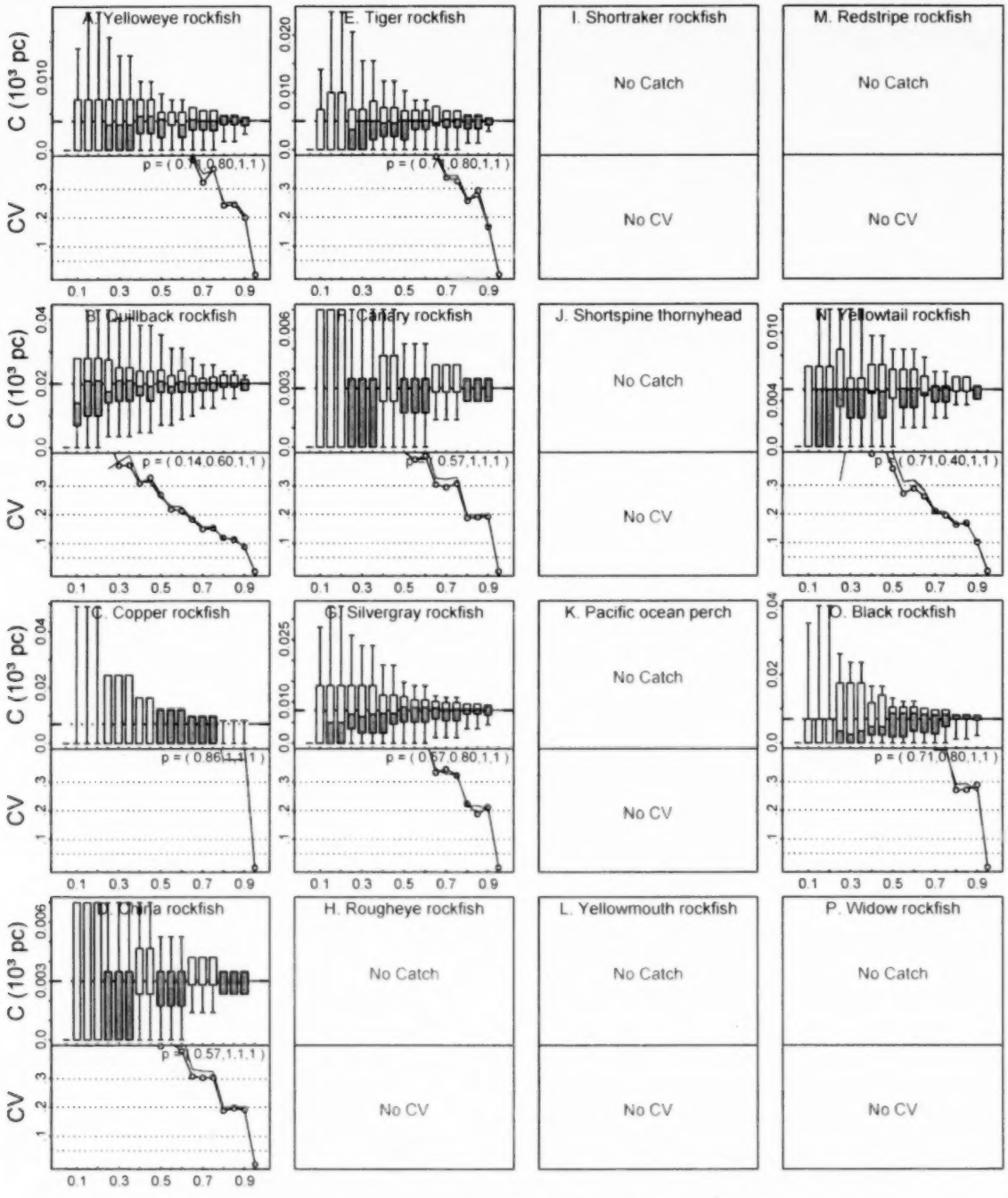

Figure 14. ZN handline fishery in PR – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 12 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

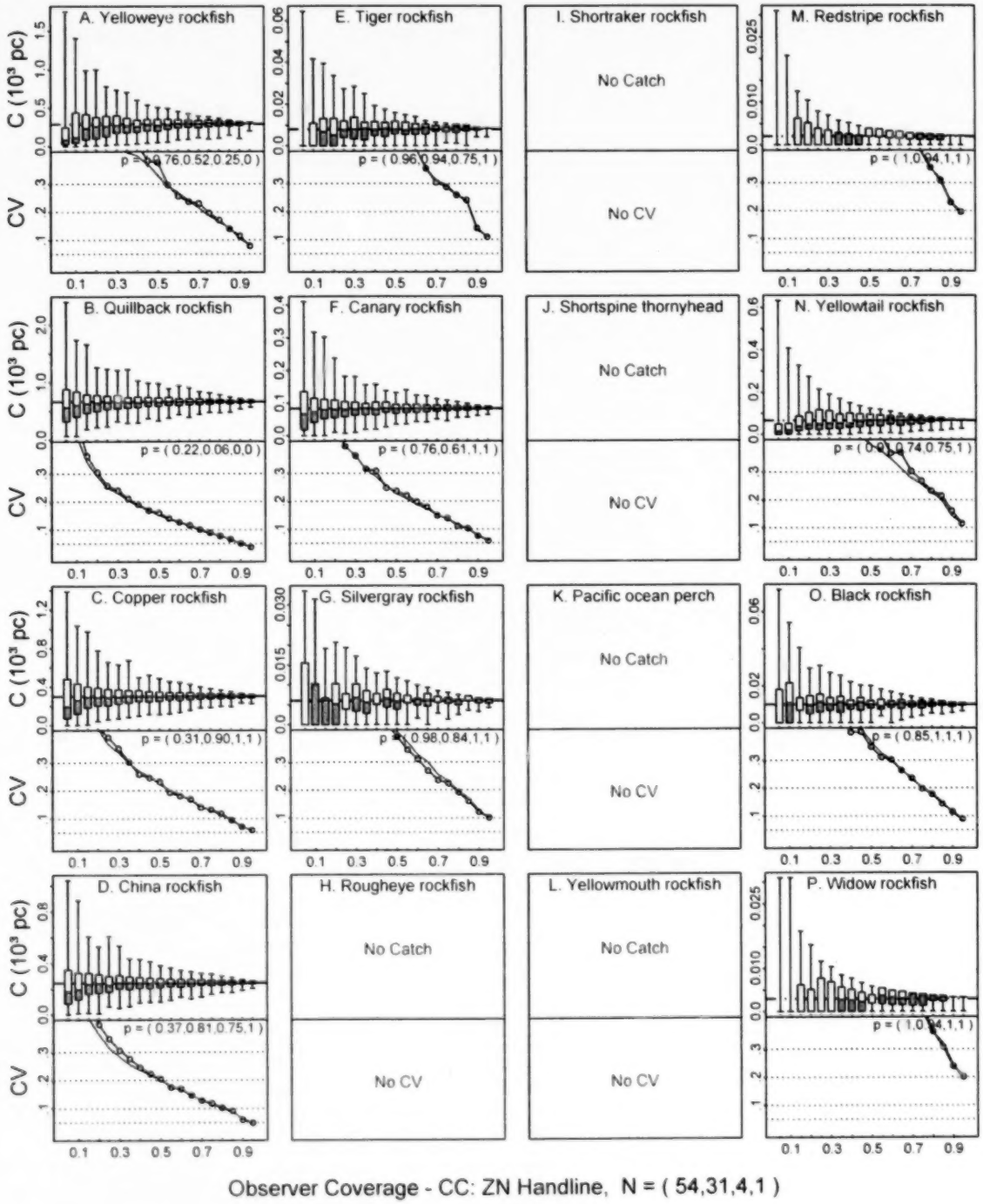

Figure 15. ZN handline fishery in CC – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 90 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

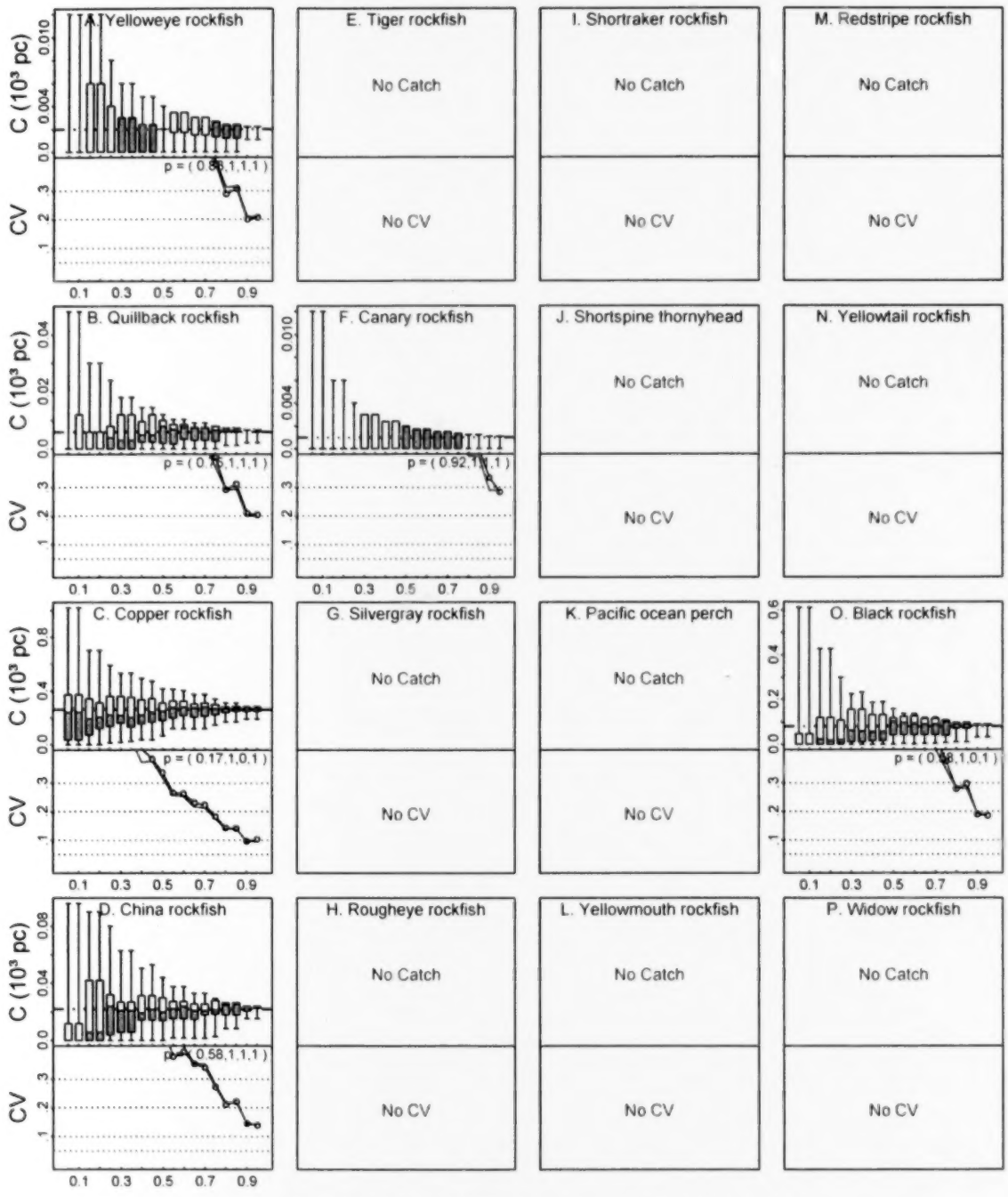

Figure 16. ZN handline fishery in WCVI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 13 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

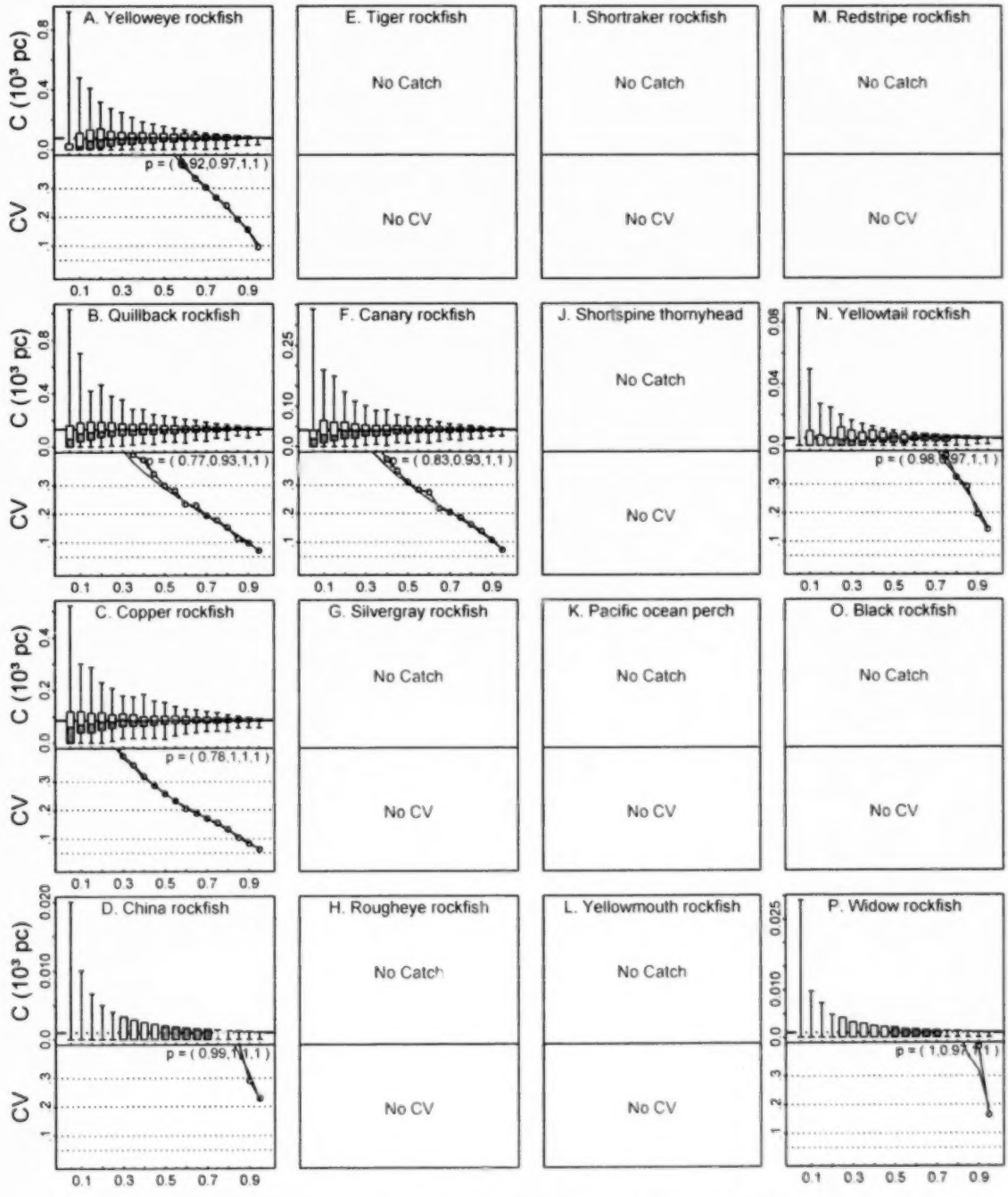

Figure 17. Schedule II longline fishery in WCVI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 129 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

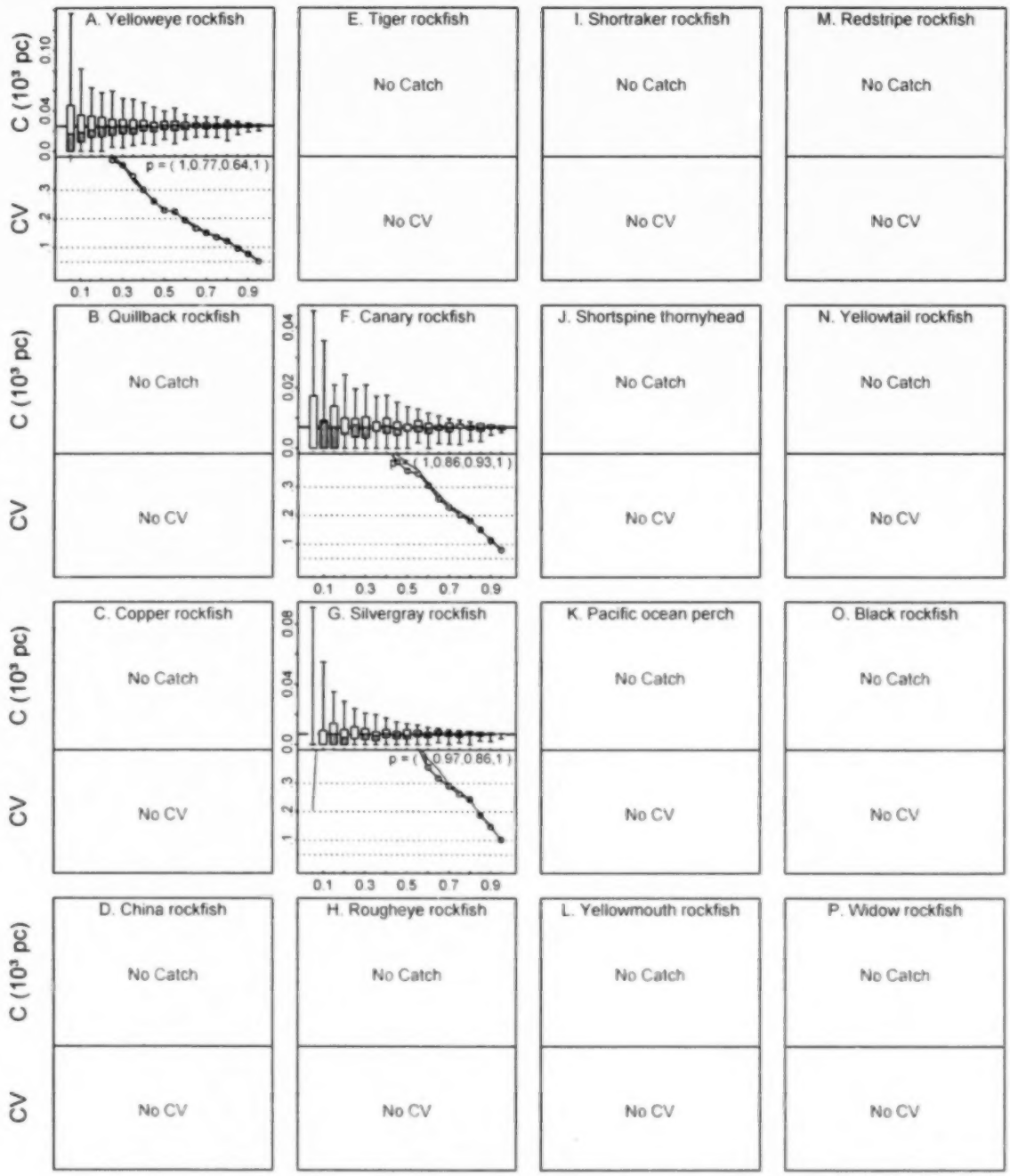

Figure 18. Schedule II troll fishery in WCVI – catch estimates $\hat{C}$ of IRF in observer sets. For each level of coverage, available sets in each depth stratum were sampled M = 500 times without replacement. Upper panel: boxplots of $\hat{C}$, horizontal red line indicates true catch in 68 observer sets. Lower panel: blue = CV of $\hat{C}$ (Eqn 5.6), red = mean of estimated CVs (Eqn 5.7). N = Number of sets in each depth stratum, p = proportion of N with zero catch.

Appendix A. Summary of sampling theory

Table A.1. Parameters for a population of size N, estimates from a simple random sample of size n drawn without replacement, and statistical properties of these estimates. Estimation from the sample requires a knowledge of the population size N.

Parameters from the population $\{y_1, \ldots, y_N\}$

(A1.1) $$\mu = \frac{1}{N}\sum_{i=1}^{N} y_i\,, \quad \tau = \sum_{i=1}^{N} y_i = N\mu$$

(A1.2) $$\sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i - \mu)^2$$

Estimates from the sample $\{y_{s1}, \ldots, y_{sn}\}$ or $\{y_1, \ldots, y_n\}$

(A1.3) $$\hat{\mu} = \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i\,, \quad \hat{\tau} = \frac{N}{n}\sum_{i=1}^{n} y_i = N\hat{\mu}$$

(A1.4) $$\hat{\sigma}^2 = s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2$$

(A1.5) $$\hat{\mathrm{V}}[\hat{\mu}] = \left(\frac{N-n}{N}\right)\frac{s^2}{n}\,, \quad \hat{\mathrm{V}}[\hat{\tau}] = \frac{N(N-n)}{n}\,s^2 = N^2\,\hat{\mathrm{V}}[\hat{\mu}]$$

Properties of the estimates

(A1.6) $$\mathrm{E}[\hat{\mu}] = \mu\,, \quad \mathrm{E}[\hat{\tau}] = \tau\,, \quad \mathrm{E}[\hat{\sigma}^2] = \sigma^2$$

(A1.7) $$\mathrm{V}[\hat{\mu}] = \left(\frac{N-n}{N}\right)\frac{\sigma^2}{n}\,, \quad \mathrm{V}[\hat{\tau}] = \frac{N(N-n)}{n}\,\sigma^2 = N^2\,\mathrm{V}[\hat{\mu}]$$

(A1.8) $$\mathrm{E}\left[\hat{\mathrm{V}}[\hat{\mu}]\right] = \mathrm{V}[\hat{\mu}]\,, \quad \mathrm{E}\left[\hat{\mathrm{V}}[\hat{\tau}]\right] = \mathrm{V}[\hat{\tau}]$$

Table A.2. Additional parameters for a population of size N with auxiliary data and ratio estimates from a simple random sample of size n drawn without replacement. Estimation from the sample with auxiliary data x_i for each individual i also requires a knowledge of the population size N, the auxiliary mean μ_x, and the total $\tau_x = N\mu_x$.

Additional parameters from the population $\{(y_1, x_1), \ldots, (y_N, x_N)\}$

(A2.1) $$\mu_x = \frac{1}{N}\sum_{i=1}^{N} x_i\,, \quad \tau_x = \sum_{i=1}^{N} x_i = N\mu_x$$

(A2.2) $$R = \frac{\sum_{i=1}^{N} y_i}{\sum_{i=1}^{N} x_i} = \frac{\tau}{\tau_x}$$

(A2.3) $$\sigma_r^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i - Rx_i)^2$$

Estimates from the sample $\{(y_{s1}, x_{s1}), \ldots, (y_{sn}, x_{sn})\}$

(A2.4) $$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i\,, \quad r = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} = \frac{\bar{y}}{\bar{x}}$$

(A2.5) $$\hat{\mu}_r = r\mu_x\,, \quad \hat{\tau}_r = N\hat{\mu}_r = r\tau_x\,, \quad \hat{\sigma}_r^2 = s_r^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - rx_i)^2$$

(A2.6) $$\hat{\mathrm{V}}[\hat{\mu}_r] = \left(\frac{N-n}{N}\right)\frac{s_r^2}{n}\,, \quad \hat{\mathrm{V}}[\hat{\tau}_r] = \frac{N(N-n)}{n}\,s_r^2 = N^2\,\hat{\mathrm{V}}[\hat{\mu}_r]$$

(A2.7) $$\tilde{\mathrm{V}}[\hat{\mu}_r] = \left(\frac{\mu_x}{\bar{x}}\right)^2 \hat{\mathrm{V}}[\hat{\mu}_r]\,, \quad \tilde{\mathrm{V}}[\hat{\tau}_r] = \left(\frac{\mu_x}{\bar{x}}\right)^2 \hat{\mathrm{V}}[\hat{\tau}_r]$$

(A2.8) $$\hat{\mathrm{V}}[r] = \left(\frac{N-n}{N\mu_x^2}\right)\frac{s_r^2}{n}\,, \quad \tilde{\mathrm{V}}[r] = \left(\frac{N-n}{N\bar{x}^2}\right)\frac{s_r^2}{n} = \left(\frac{\mu_x}{\bar{x}}\right)^2 \hat{\mathrm{V}}[r]$$

Table A.3. Properties of the estimates in Table A.2.

(A3.1) $$\mathrm{E}[\hat{\mu}_r] \approx \mu\,, \quad \mathrm{E}[\hat{\tau}_r] \approx \tau\,, \quad \mathrm{E}[s_r^2] \approx \sigma_r^2$$

(A3.2) $$\mathrm{V}[\hat{\mu}_r] \approx \left(\frac{N-n}{N}\right)\frac{\sigma_r^2}{n}\,, \quad \mathrm{V}[\hat{\tau}_r] = N^2\,\mathrm{V}[\hat{\mu}_r]$$

(A3.3) $$\mathrm{E}[r] = R - \frac{\mathrm{Cov}[r,\bar{x}]}{\mu_x} \approx R$$

(A3.4) $$\frac{|\mathrm{E}[r]-R|}{\sqrt{\mathrm{V}[r]}} \leq \frac{\sqrt{\mathrm{V}[\bar{x}]}}{\mu_x}$$

Appendix B. Current status of observer programs on Canada's west coast

Groundfish by trawl:

Option A: 100 % mandatory observer coverage is a requirement for all vessels participating in the IVQ (Individual Vessel Quota) groundfish trawl fishery under the Option "A" groundfish licence. The fishery has ~50-70 active vessels and is open year round. Observers quantify catch, utilization (retained or discarded), assess condition of halibut, verify compliance to a complex licence and management policies and collect biological samples and information to DFO specifications. The program was initiated in 1996 to address concerns over gross misreporting of catch, area of catch, at-sea releases, and retention of illegal species. Objectives of this mandatory program are to instil a high level of accountability on the fleet at the individual fisher level, to gather thorough observations by unbiased independent means, and collect accurate catch, effort and fishing activity information for this fleet. Data from the observer program is the basis for the assessment of most groundfish species as well as the primary source of biological samples from this fishery.

The exception to the 100% observer requirement for "Option A" trawl is when vessels fish mid-water for Hake. Prior to 2002 there has was no requirement for observer coverage in the directed midwater hake fishery in either the offshore (3C/D) or Gulf (4B) fisheries. Since 1987 DFO has relied upon the 100% at-sea observers coverage onboard factory ships participating the joint-venture fishery as the primary sources of biological and catch information from the offshore hake fishery. For the inside Gulf fishery DFO has been dependant on fisher logbooks and sampling by port samplers to characterize the fishery. For the 2002-season a target observer coverage of 10% of sea-days was implemented, for both inside and outside, using the rationale that with the elimination of the JV fisheries there was no opportunity to collect site specific biological samples, no opportunity to collect independent catch and effort data and most importantly no way to account for all catch and by-catch for this fleet. Observers will record detailed catch and effort data and collect biological samples as specified by DFO. Funding of the cost of the observer presence on the vessel for the 2002 program is cost recovered from the industry.

Option B: Trawl vessels participating in this fishery are restricted to fishing in Inside waters in the Strait of Georgia (4B). Fishing activity is not under the IVQ program but is regulated through monthly vessel trip limits. This fleet (approximately 10-14 active vessels) are generally small and fish year round delivering small quantities of groundfish to live or fresh markets on Vancouver Island and the Lower mainland. This fishery is not subject to mandatory observer coverage. Coverage has been constrained by requiring the co-operation of the fleet and by the limited financial resource of the DFO. This program was formalized for the 2002 season with an initial target coverage of 10 % or roughly 100 sea-days. Observers collect the same information for this fleet as has been collected by observers monitoring the "Option A" fleet.

Shrimp Trawl: The fishery is managed through a series of time, area and quota restrictions. An observer program was implemented for this fishery in 1997 to address concerns over Eulachon and Halibut bycatch in this fishery. The target coverage level was 50 days per year or approximately 1 %. Coverage has varied between 43 and 93 days. The observer records detailed catch and by-catch information and collects samples of Eulachon. These observers have been

used in some years to monitor target harvest levels for by-catch species i.e., a 40 tonne catch cap for Eulachons on the west coast of Vancouver Island. The target level for observer coverage for 2002-2003 fishing season remains at 50 days or 1%. The cost of observer coverage for the 2002 season will be borne by DFO.

The current levels of observer coverage targeted and the levels of coverage achieved by each fishery are presented in Tables B.1 and B.2, respectively.

Groundfish by Hook and Line:

Halibut by Hook and Line: The Halibut fishery is assessed, and national harvest levels established by, the International Pacific Halibut Commission (IPHC). Since 1991, the Canadian fishery has operated under an IVQ program. There was no mandatory requirement for observer coverage prior to 1999 at which time an observer program was implemented due to concerns over by-catch, particularly of inshore rockfish, the level of retention and discarding, and seabird interactions with the gear. Coverage levels have been increasing since being implemented in 1999 to the current target level of 15 % or 1070 sea days. In 2002 DFO in conjunction with the industry initiated a study to achieve an additional 10 % coverage through a combined Video/GPS "Black Box" monitoring system. Analyses of the study data may impact future coverage requirements for this and other fleets. Funding of the cost of the observer presence on the vessels for the 2002 program is cost recovered from the industry. This fishery is typically open from March 15-November 15.

ZN - Rockfish by Hook and Line - Outside: This fishery targets rockfish specifically using longline or troll gear. License holders can select one of four options in this fishery, which determines the combination of species they will be targeting. The fishery is managed through a series of area and quota restrictions. The target level of observer coverage has been set at 10 % for each of the options. It is expected that a combined total of 235 days (Table B.1) will be realised for the 2002 fishing year. Observer coverage is mandatory for vessels when requested by DFO. The goals of the program are to account for all catch, especially inshore rockfish, determine seabird avoidance and interactions with gear and to document fishing activities for observed vessels for possible use in determining fleet compliance. Prior to the 2002 season, observer coverage was not mandatory despite the need for better accounting of catch and effort for this fleet. Past levels of observer coverage achieved were severely limited by requiring co-operation from fishers and by DFO funding limitations. Funding of the cost of the observer presence on the vessel for the 2002 program is cost recovered from the industry.

ZN - Rockfish by Hook and Line - Inside: This fishery also targets rockfish and operates in Major Area 4B: the Strait of Georgia, Strait of Juan de Fuca, Johnstone Strait and Queen Charlotte Strait. Observer coverage of 50 days had been mandated for this fishery for the 2002-03 fishing season but due to closure of the fishery is no longer an issue. Observer coverage was mandated to address concerns over level of catch, anecdotal reports of high-grading, discarding of lower valued or non-retainable species and seabird avoidance and interactions with gear. The fishery has been managed through a series of area and quota restrictions.

Schedule II - Other groundfish by Hook and Line: This fishery primarily targets lingcod and dogfish. Due to reduced opportunities in other fisheries there has been a large increase in participation in this fishery over the last 5 years. Concerns primarily with the level of bycatch and discarding of inshore rockfish species and seabird avoidance and interactions with gear lead to a limited co-operative observer program being initiated in the 2001-02 season. The initial level of observer coverage was set at 50 sea-days, this was achieved for the 2001-02 season. For the 2002-03 fishing season the target level of observer coverage has been increased to 10%, which corresponds to approximately 205 days (Table B.1). The fishery is managed through a series of time, area and quota restrictions. Funding of the cost of the observer presence on the vessel for the 2002 program is cost recovered from the industry.

Sablefish by Longline: Vessels participating in this fishery can use either longline hook and line or trap gear to harvest Sablefish under an IVQ management plan. Prior to 2001 there was no requirement for observer coverage in this fleet. To address a lack of information on bycatch and seabird avoidance and interactions with gear, observer coverage was mandated for the 2001-02 fishing season to quantify the levels, and the usage, of bycatch. Observers also collect detailed catch and effort data as well as biological samples of sablefish for DFO. The current target coverage level is 10 % or approximately 100 days (Table B.1). This fishery season runs from August to July and is usually open year round. Funding of the cost of the observer presence on the vessel for the 2002 program is cost recovered from the industry.

Table B.1. Target levels of observer coverage by fishery for the 2002-03 fishing season.

Fishery	Gear	Percentage Coverage Target	Targeted Days
IVQ Groundfish Trawl	Bottom/Midwater trawl	100%	5800
IVQ Hake Trawl	Midwater Trawl	10%	100
Inshore Groundfish Trawl	Bottom/Midwater trawl	10%	100
Shrimp Trawl	Bottom	1%	50
IVQ Halibut	Hook and line	15%	1075
ZN Rockfish	Hook and line	10%	235
Outside option A		10%	100
Outside option B		10%	60
Outside option C		10%	75
Inside		10%	0
Sablefish	Hook and line/Trap	10%	100
Groundfish other (schedule II)	Hook and line	10%	205
Lingcod		10%	120
Dogfish		10%	82
Totals			7665

Table B.2. Levels of observer coverage achieved between 1996 and 2001 for all groundfish fisheries.

Year	Option A Trawl	Option B Trawl	Halibut	Hook and Line	Sablefish	Shrimp Trawl	Joint Venture Hake	Hake	Misc Other Fisheries	Total
1996										
1997										
1998	5,338	-	-	-	-	93	547	-	17	5,994
1999	5,839	-	142	43	-	53	200	-	42	6,319
2000	5,788	-	161	21	2	43	828	-	60	6,903
2001	5,732	34	524	119	6	81	369	-	-	6,865
2002 targets	5,800	100	1,075	440	100	50	-	100	-	7,665

Appendix C. Request for advice

Date submitted: September 20, 2002
Group requesting advice: Groundfish Management Unit
PSARC presentation date: November 13, 2002
Subject of Paper: Assessment of partial coverage at sea catch monitoring programs in BC hook and line groundfish fisheries
Lead author: Rowan Haigh
Fisheries management: Carole Eros, Rob Wright, Barry Ackerman, Gerry Dunsmore

Rationale for request:

In response to a lack of total catch information (retained and released) and a conservation concern for the inshore rockfish species group in B.C., partial coverage at sea catch monitoring programs were recently initiated for commercial groundfish fisheries in B.C. While a dockside monitoring program accounts for all landed catch, anecdotal evidence suggests that at-sea releases of rockfish in these fisheries is potentially significant. The lack of such information currently limits the Department's capability to estimate total fishery mortality and exploitation rates, and manage fisheries to ensure catches remain within sustainable total allowable catch levels.

The objective of the at-sea programs was to begin to collect data to develop estimates of at sea releases of inshore rockfish. These partial coverage programs are currently operational in the following commercial licence category groundfish fisheries: L (halibut hook and line), K (sablefish hook and line and trap), Outside ZN (rockfish hook and line), Schedule II (dogfish and lingcod hook and line), and T (Option B trawl, Option A mid-water trawl for hake).

The target levels of partial coverage for the ASOP's varies by fishery, but generally covers 10-15% of the fishing effort (vessel days and boat trips). This level of coverage was developed without a scientific basis that addresses issues of accuracy and precision. In assessing and establishing coverage levels, it is vital to know the precision associated with each coverage level as it is important for the Department to be able to provide an objective rationale for a required level of at sea catch monitoring for the commercial groundfish fisheries.

The need for effective catch monitoring and catch monitoring standards has been highlighted in a number of departmental policy initiatives (i.e., *New Directions*, *Selective Fishing*, *Allocation for Pacific Salmon*, *Pacific Fishery Monitoring and Reporting Framework*) and is fundamental to meeting Canada's international obligations.

Questions to be addressed in the Working Paper:

1. What is the status of the commercial groundfish at sea catch monitoring programs in BC?
2. What are the total catch estimates for inshore rockfish by fishery, gear type, rockfish management area and depth?
3. What is the level of confidence in these catch estimates with regards accuracy and precision?
4. What modifications in the at sea monitoring programs with respect to level of coverage and design would improve the accuracy of the catch estimates?

Objective of Working Paper:

1. Estimate the total catch of inshore rockfish by species and aggregate groups for each fishery (Halibut, ZN, Schedule II) by gear type, area and depth.

2. Evaluate the precision and accuracy of the catch estimates at varying levels of observer coverage.

3. Identify the biases, strengths and weaknesses of the use of partial at-sea monitoring programs to determine catch estimates of inshore rockfish.

4. Recommend options and strategies to improve the accuracy of catch estimates and formulate rationale and methodology for use when initiating and evaluating the level of at-sea coverage in fisheries.